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THE EMITTANCE OF CERAMICS AND GRAPHITES

DEFENSE METALS INFORMATION CENTER

BATTELLE MEMORIAL INSTITUTE

COLUMBUS 1, OHIO

THE EMITTANCE OF CERAMICS AND GRAPHITES

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INTRODUCTION

There has been, for some years, a considerable interest in data on the thermal properties of materials. Many of these data are reported in an excellent manner by Armour Research Foundation in WADC TR-58-476, Volumes I through IV. Data available through 1957 are included.

Recently there has been an increased and particular interest in the radiant heat transfer and thermal-radiation properties. The fundamentals and nomenclature of radiant heat transfer are often not familiar to those who now find themselves concerned with it.

The Defense Metals Information Center has prepared a series of memorandums in the general field of radiant heat transfer to make this information and the data on thermal-radiation properties more readily available. Each memorandum is being directed toward providing information in a particular area of interest. Included are basic fundamentals, definitions and methods used in measuring the radiant-heat-transfer properties of materials, as well as literature values of these properties for selected materials. This series of memorandums ultimately will be assembled into a report for those with a broad interest in radiant heat transfer.

This present memorandum is the last of the series and is a compilation of original test data on emittance, reflectance, and transmittance of ceramics and graphites. Although these materials are on the borderline of the DMIC scope, the data were uncovered during the general search and are included to complete the record. The data were taken from the literature published during the period 1940-1959, inclusive, and as much of the 1960 literature as could be obtained. The following sources were searched: Chemical Abstracts, Ceramic Abstracts, Metallurgical Abstracts, Nuclear Science Abstracts, and the files of the Defense Metals Information Center (DMIC). The authors have attempted to evaluate these scurces of data according to the apparent thoroughness of methods and techniques as described by the various investigators. In many cases the descriptions in the literature are a summary of methods and results, and a complete evaluation is impossible. With these considerations in mind the authors have shown curves which, in their estimation, indicate the most probable values for the various conditions and materials.

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METHOD OF PRESENTATION OF DATA

The data have been separated according to material and to the type of measurement, whether spectral or total.

In previous publications of this series, emittance data are given as the complement of the reflectance, which assumes a sample opaque to the radiation concerned in each case. Many of the ceramic materials transmit considerable amounts of incident radiation and must be relatively thick to be effectively opaque. The data in this memorandum are, therefore, given only in the units measured by the investigators, since for most cases the emittance must be considered as the complement of the sum of the reflectance and the transmittance.

All data have been plotted with each reference shown by different symbols. The reference-information sheet accompanying each graph gives the names of the investigators and the number of the reference from which the data were obtained. Notations of composition and surface condition of the sample tested, and a brief notation on the methods and conditions of measurement, are given when available.

The curves drawn by the authors have been prepared with special emphasis on the extremes found in the literature for the polished and oxidized conditions. The information for other surface conditions is contained in the accompanying reference-information sheet.

Further information concerning methods used may be found in the particular reference given or in DMIC Memorandum No. 78, "Methods of Measuring Emittance".

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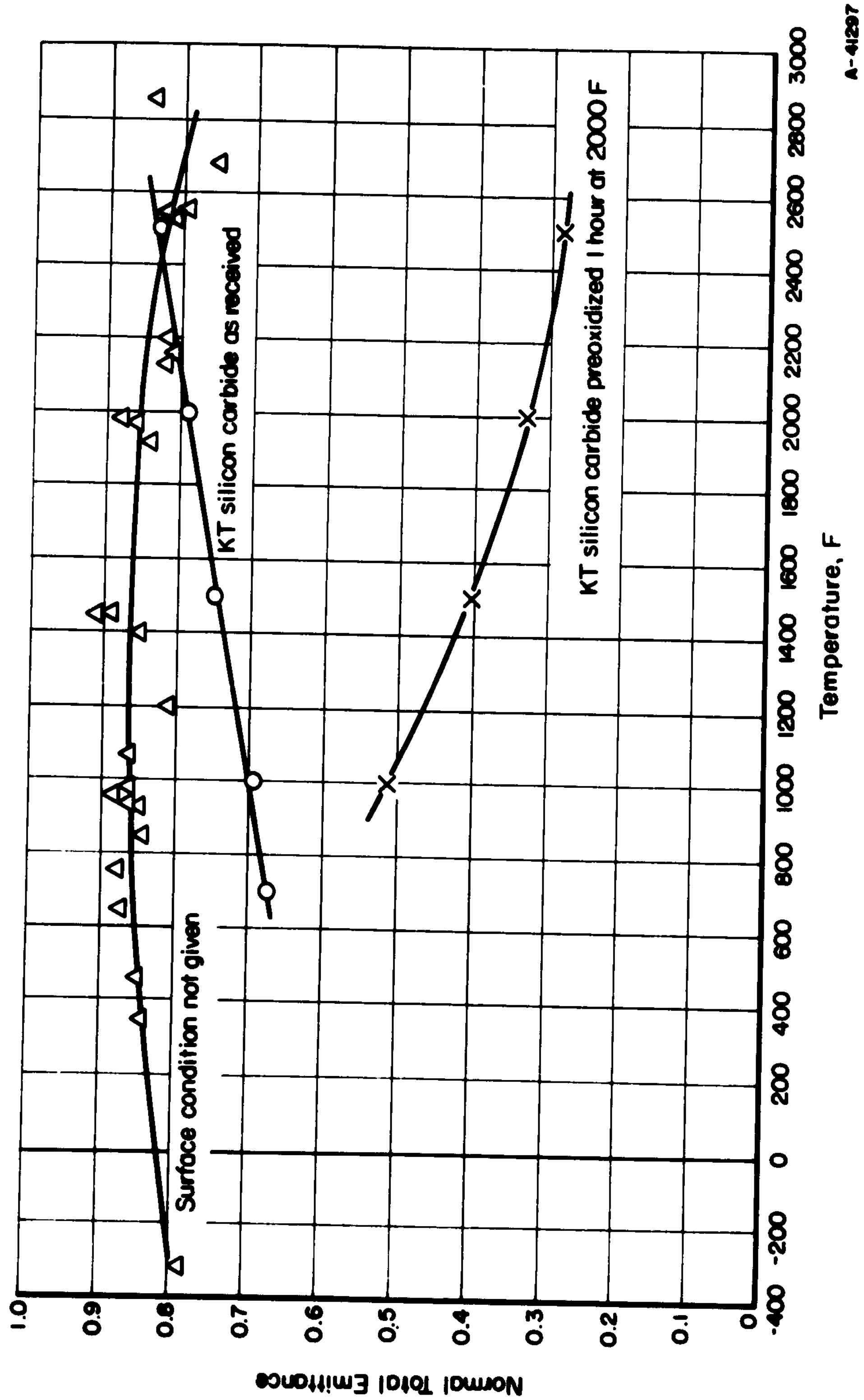
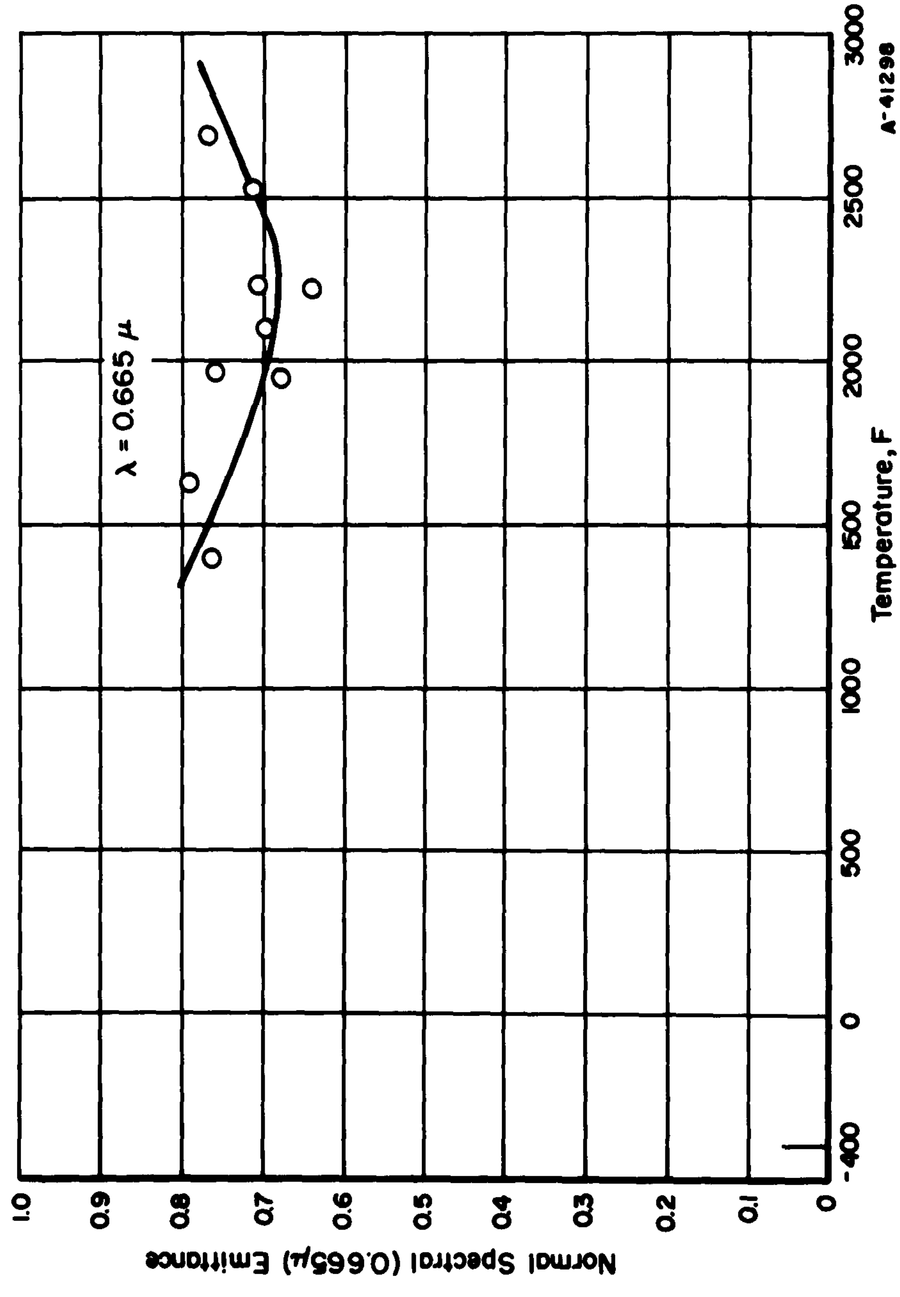
EMITTANCE DATA



NORMAL TOTAL EMITTANCE OF SILICON CARBIDE

NORMAL TOTAL EMITTANCE OF SILICON CARBIDE--REFERENCE INFORMATION

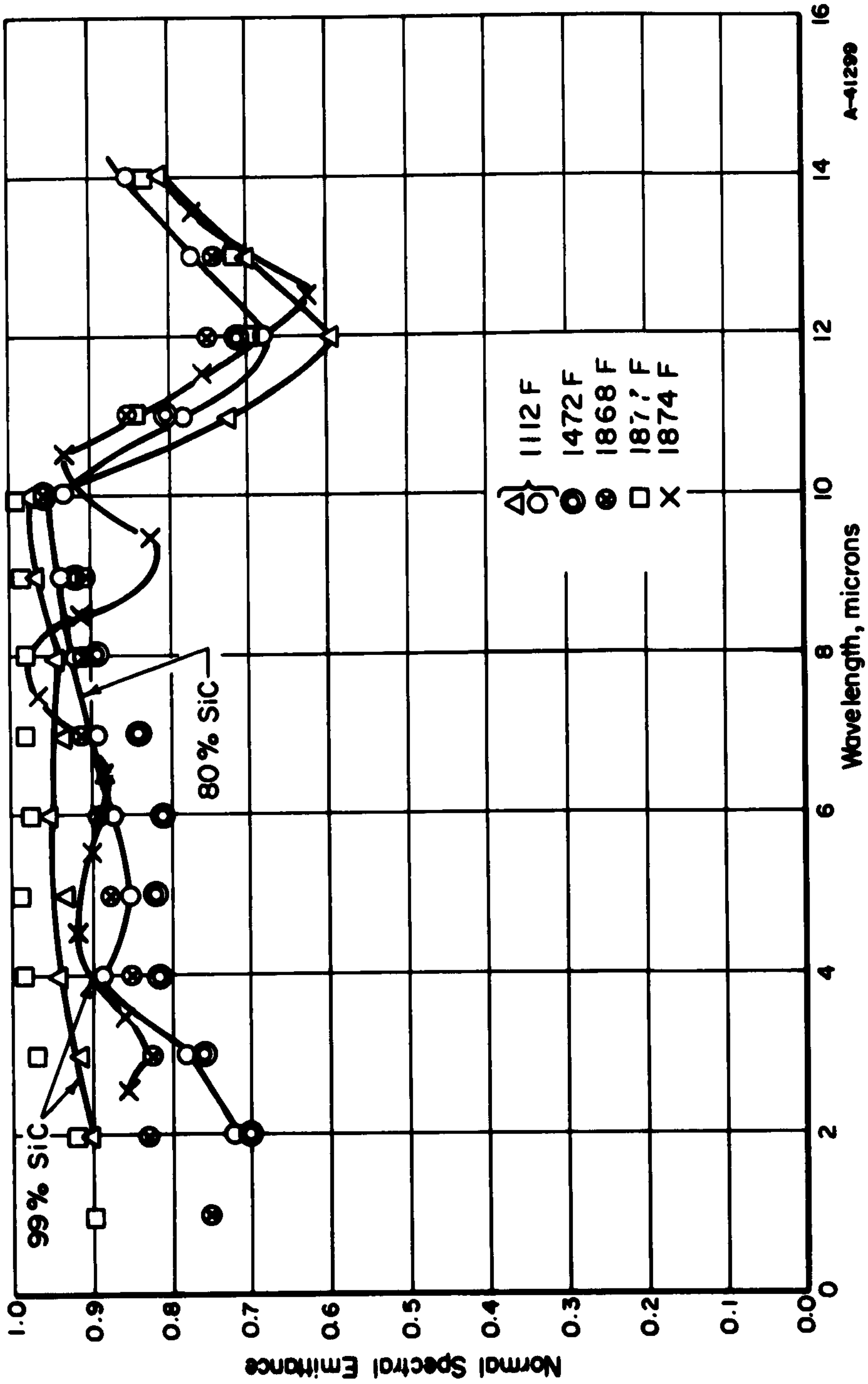
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
1	Anthony and Pearl		KT Silicon carbide	Normal total emittance. Induction-heated specimen. Comparison blackbody. Thermopile detector. Temperatures measured with thermocouples.	Measured in purge of dry helium gas. Data taken from table.
		○	As received		
		×	Pre-oxidized in air 1 hour at 2000 F		
2	Olson and Morris	△	Silicon carbide Surface condition not given	Normal total emittance. Furnace-heated specimen. Comparison blackbody. Thermistor detector. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.



NORMAL SPECTRAL EMITTANCE OF SILICON CARBIDE

NORMAL SPECTRAL EMITTANCE OF SILICON CARBIDE—REFERENCE INFORMATION

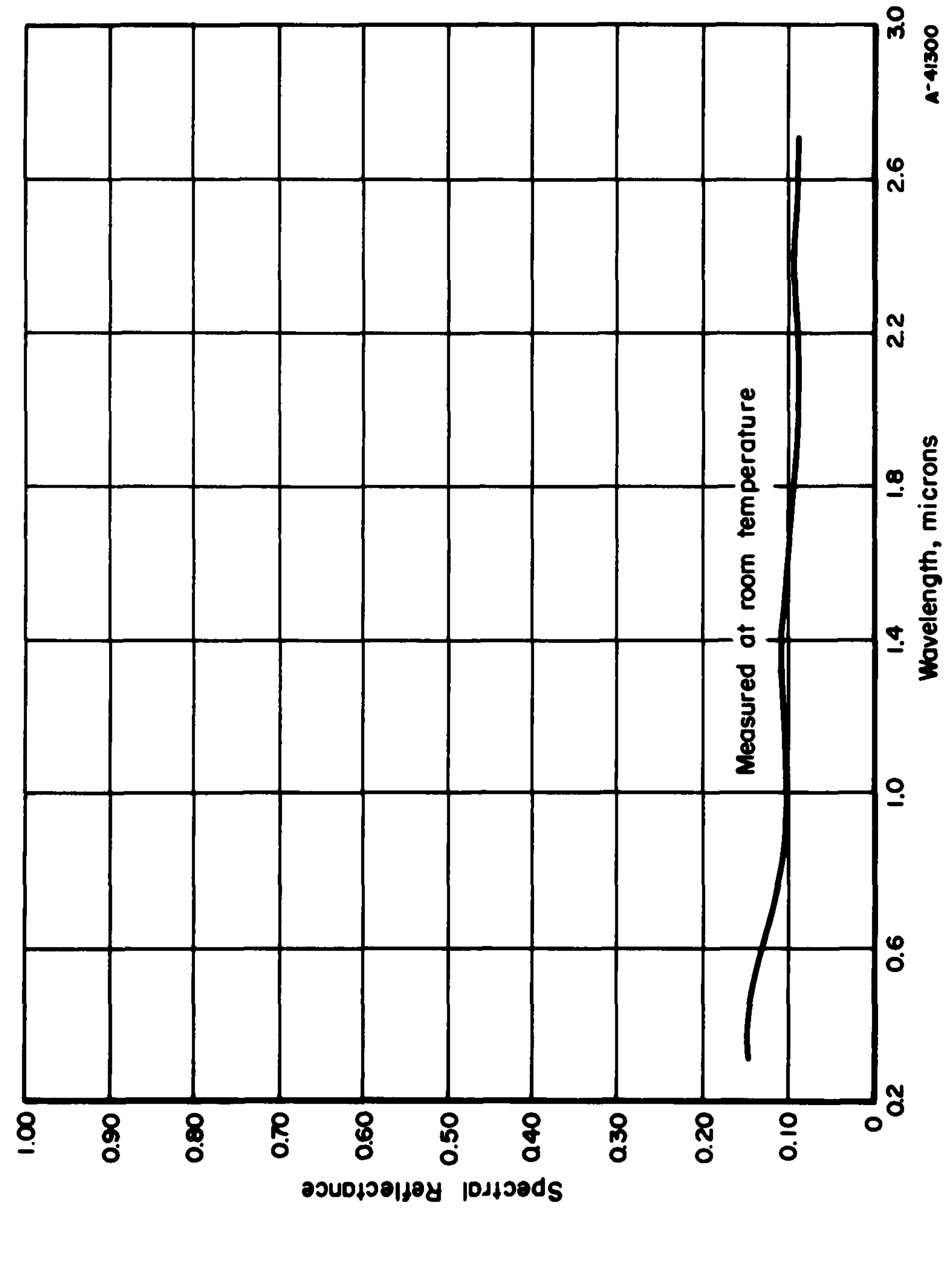
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris	O	Silicon carbide Surface condition not given	Normal spectral emittance. Furnace-heated specimen. Comparison blackbody. Commercial detector and filter system for peak response at 0.665 μ. Temperatures measured with thermocouples.	Measured in air. Data taken from curves. (λ = 0.665 μ)



NORMAL SPECTRAL EMITTANCE OF SILICON CARBIDE

NORMAL SPECTRAL EMITTANCE OF SILICON CARBIDE—REFERENCE INFORMATION

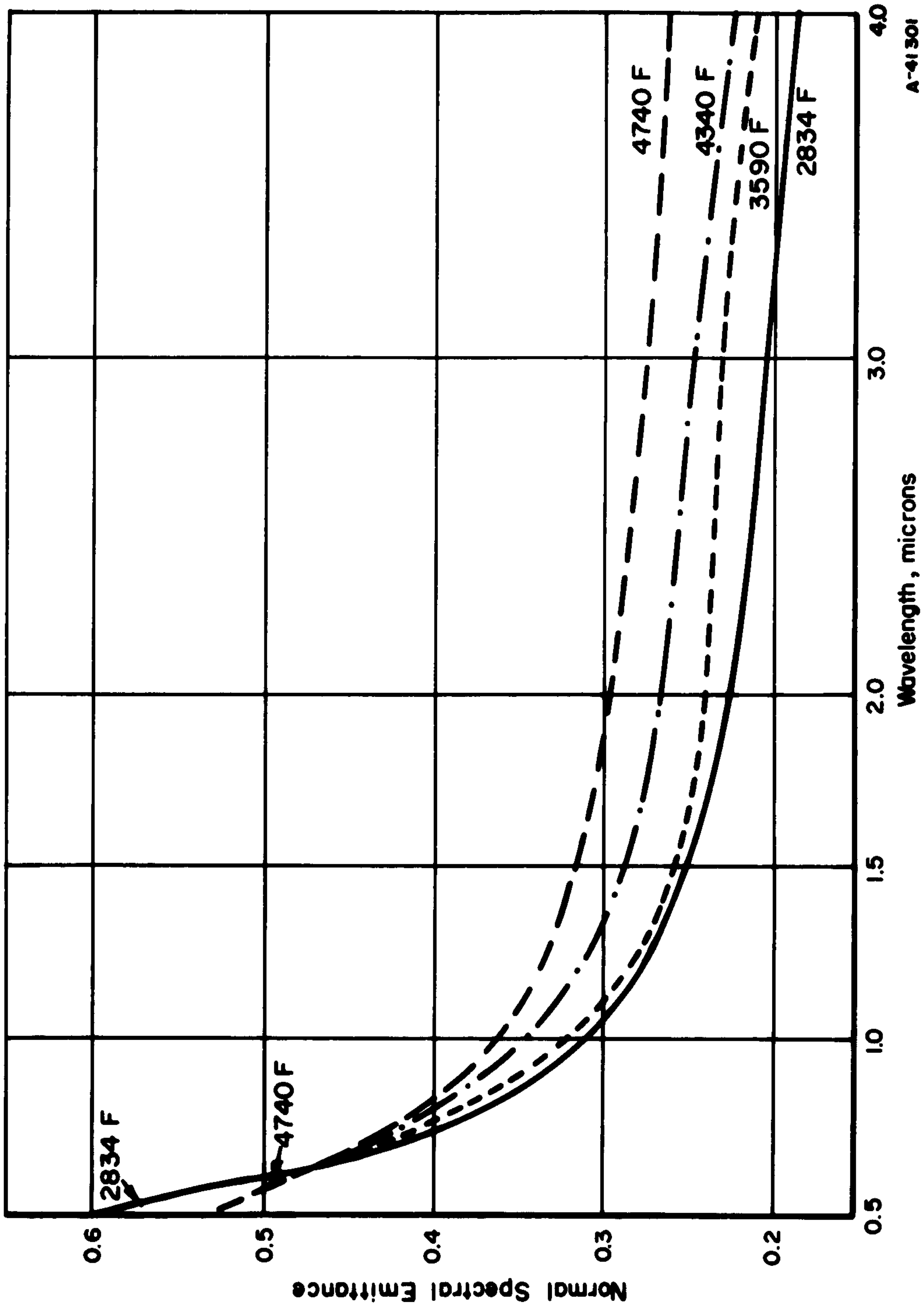
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
3	Blau, Marsh, Martin, Jasperse, and Chaffee		Silicon carbide Diamond wheel finish as supplied by manufacturer Crystolon R (Norton) 99% + pure	Normal spectral emittance. Specimen mounted in wall of cylindrical Globar (SiC) heater. Comparison blackbody hole also in heater wall. Temperatures measured with thermocouples. Monochromator and thermocouple detector.	Measured in air. Data taken from curves. (Curves are drawn through the 1112 F points only.)
		△	Measured at 1112 F		
		□	Measured at 1877 F		
			RC4237 (Norton) 80% pure		
		○	Measured at 1112 F		
		⊙	Measured at 1472 F		
		⊗	Measured at 1868 F		
4	Blau, Chaffee, Jasperse, and Martin	×	99 per cent silicon carbide (Norton Crystalon R) Flat smooth surface from diamond wheel cutting. The minima at about 9 and 12 microns are attributed to a thin SiO_2 surface film. Measured at 1874 F	Normal spectral emittance. Induction-heated specimen. Comparison blackbody. Monochromator and thermocouple detector. Temperatures measured with micro-optical pyrometer.	Measured in 90% argon, 10% hydrogen atmosphere. Data taken from curve.



SPECTRAL REFLECTANCE OF SILICON CARBIDE

SPECTRAL REFLECTANCE OF SILICON CARBIDE—REFERENCE INFORMATION

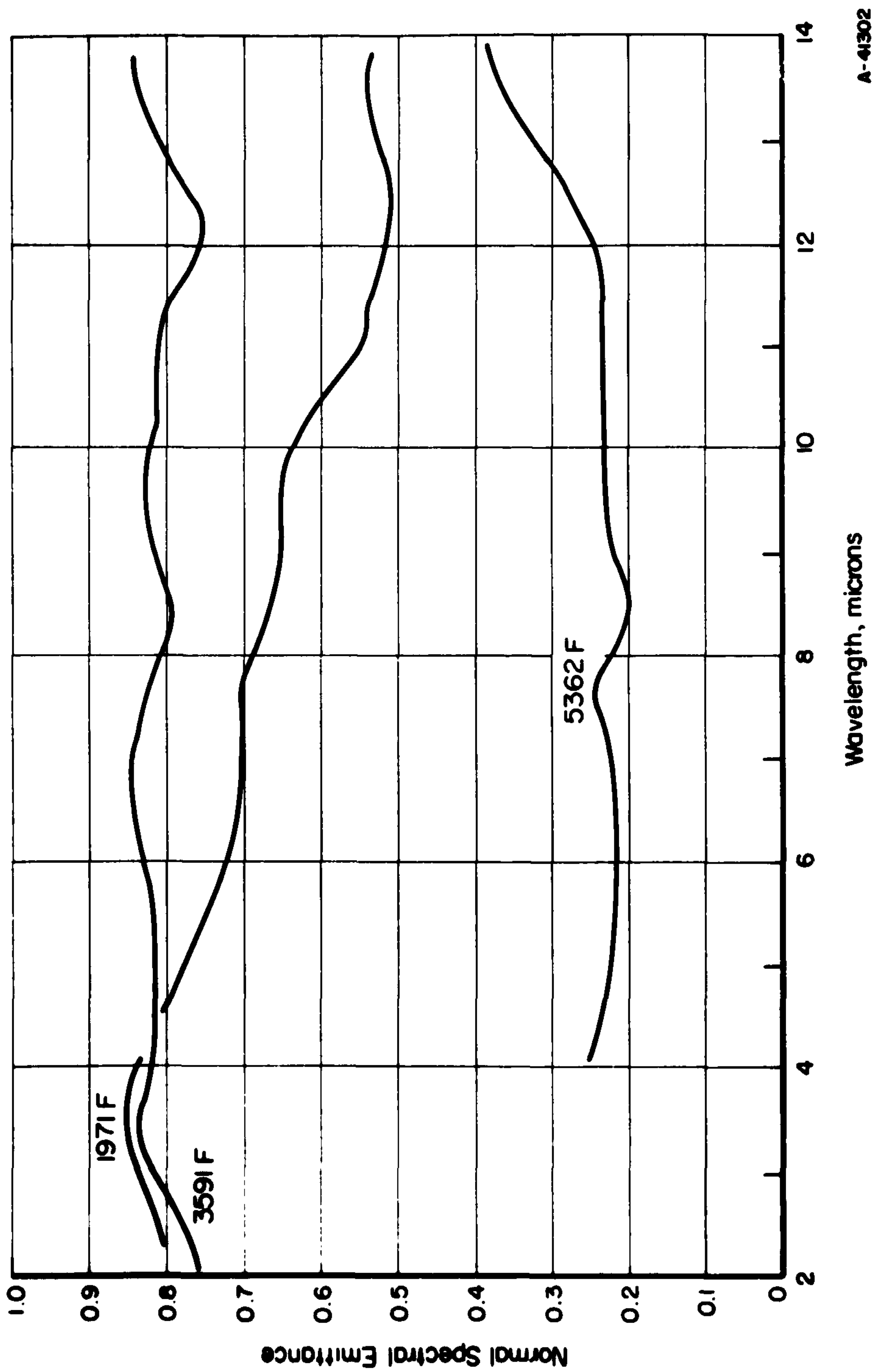
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris		Silicon carbide, purity and surface condition not given	Spectral reflectance. Incident radiation 9 degrees from normal to specimen surface. Integrating sphere reflectometer. Monochromator and lead sulphide detector. Normal (9 degrees) illumination Diffuse reflection.	Measured in air at room temperature. Data taken from curves.



NORMAL SPECTRAL EMITTANCE OF TANTALUM CARBIDE (0.5 TO 4 MICRONS)

NORMAL SPECTRAL EMITTANCE OF TANTALUM CARBIDE (0.5 TO 4 MICRONS)—REFERENCE INFORMATION

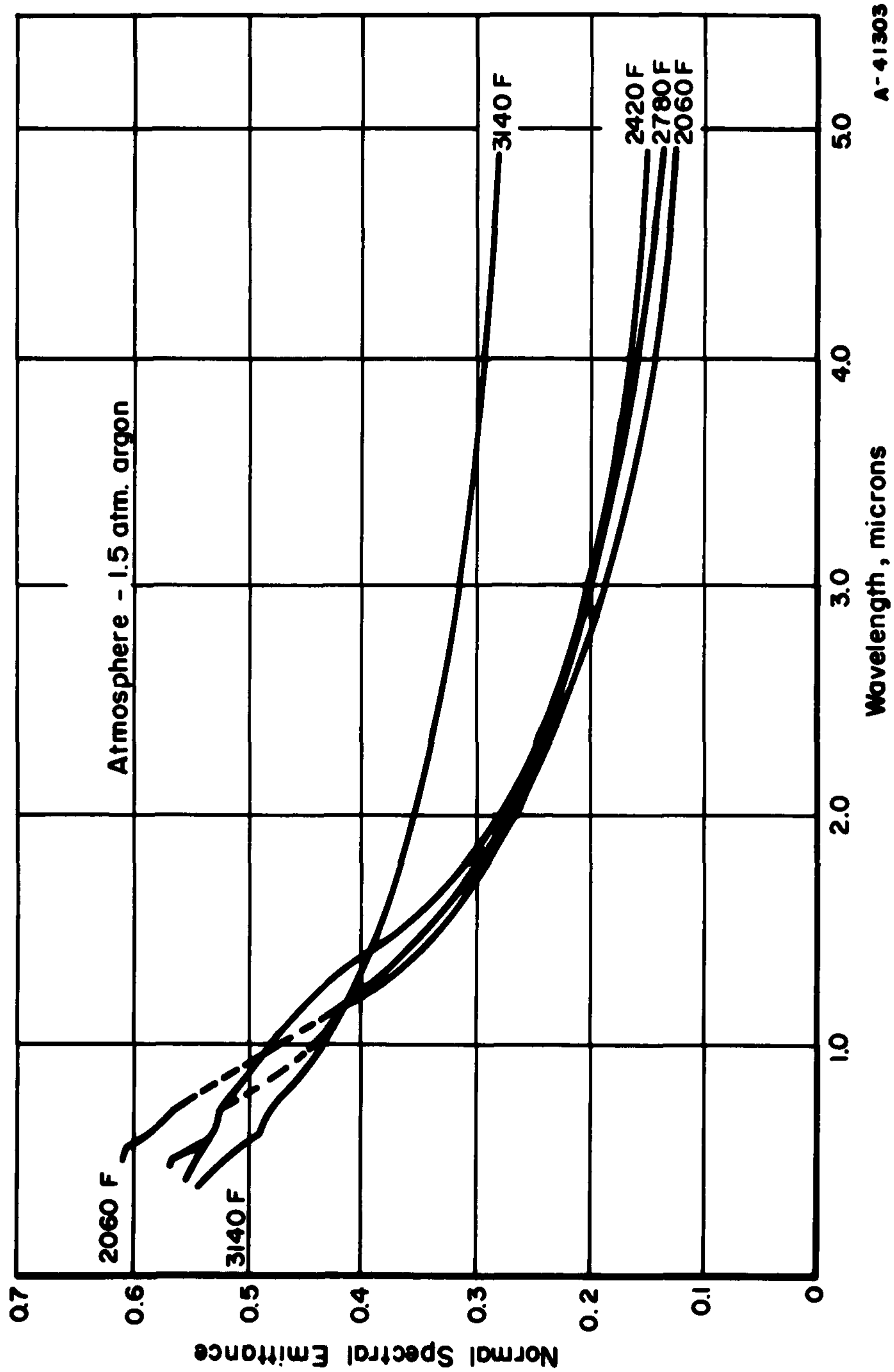
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
6	Riethof		Tantalum carbide Composition or surface condition not given Measured at 2834, 3590, 4340, and 4740 F	Normal spectral emittance. Induction-heated specimen. Blackbody hole in specimen surface. Thermocouple detector. Monochromator. Temperatures measured with optical pyrometer.	Measured in argon. Data taken from curves.



NORMAL SPECTRAL EMITTANCE OF TANTALUM CARBIDE (2 TO 14 MICRONS)

NORMAL SPECTRAL EMITTANCE OF TANTALUM CARBIDE (2 TO 14 MICRONS)—REFERENCE INFORMATION

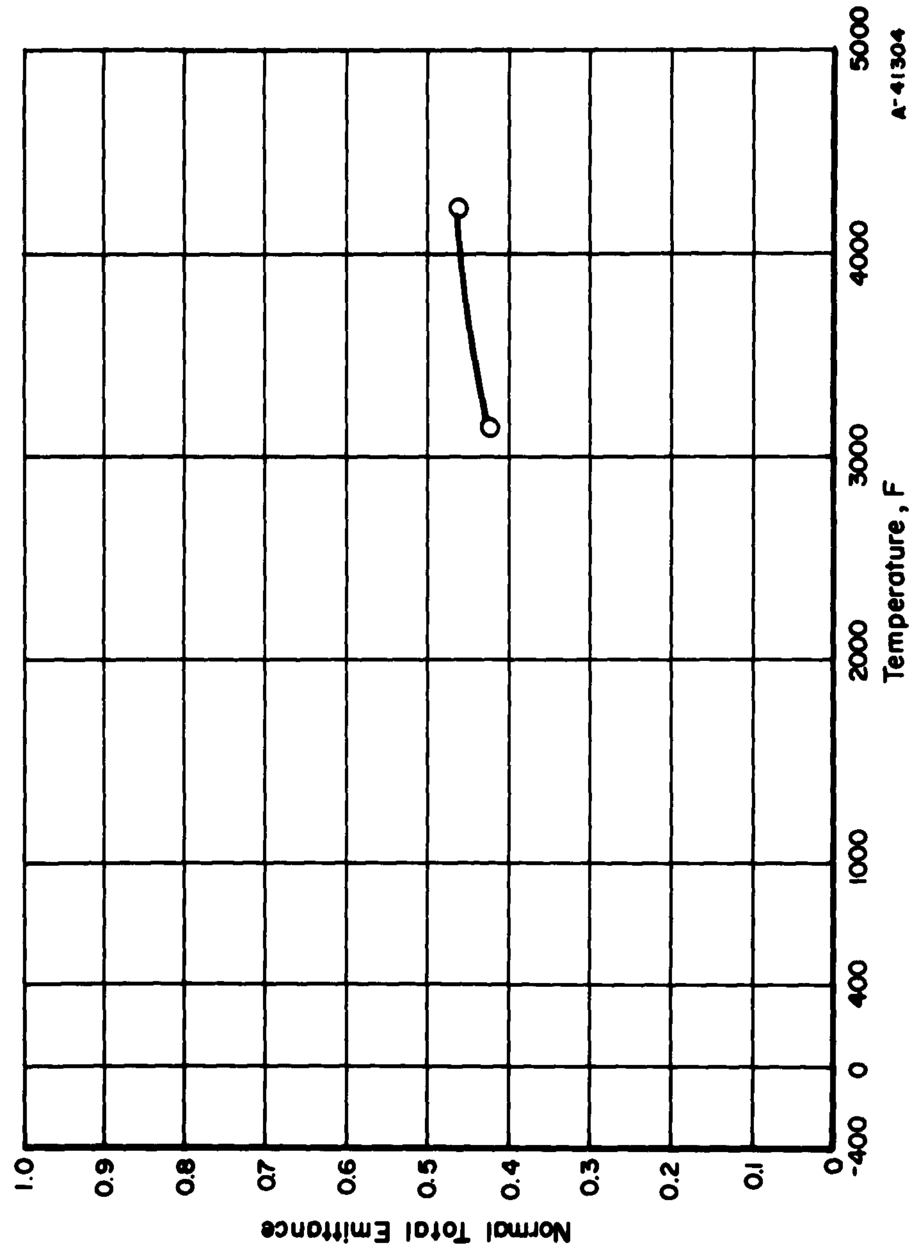
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
4	Blau, Chaffee, Jasperse, and Martin		Tantalum carbide Purity not given Surface flat and smooth but not polished (Note: Surface analysis after 3234 K (5362 F) run showed thin tantalum oxide film)	Normal spectral emittance. Induction-heated specimen. Comparison blackbody. Monochromator and thermocouple detector. Temperatures measured with optical pyrometer.	Measured in 90% argon 10% hydrogen atmosphere. Data taken from curves.



NORMAL SPECTRAL EMITTANCE OF TUNGSTEN CARBIDE

NORMAL SPECTRAL EMITTANCE OF TUNGSTEN CARBIDE--REFERENCE INFORMATION

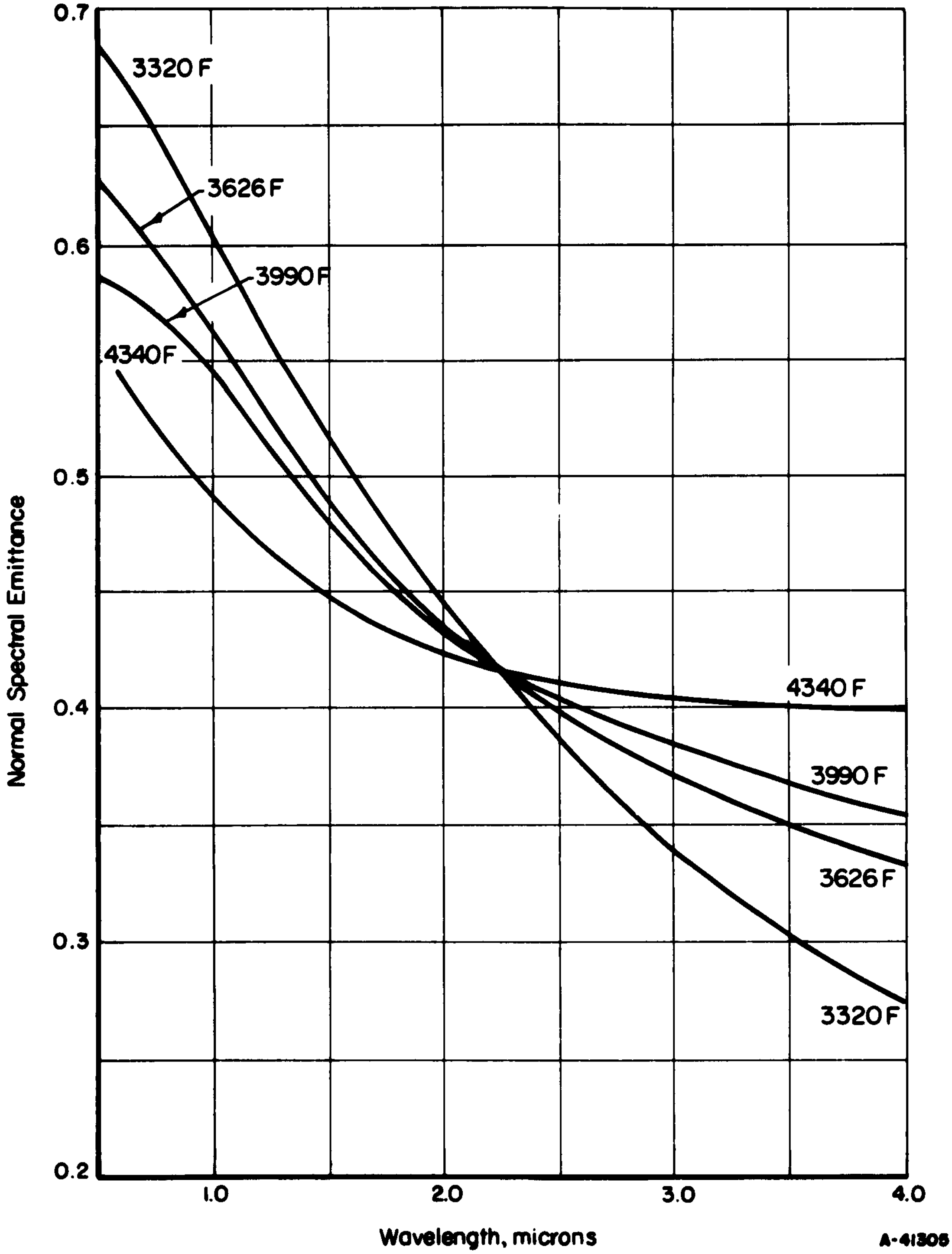
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
5	Coffman, Coulson, and Kibler		Tungsten carbide (WC) Surface condition or purity not given Note: Surface transformation from WC to W_2C at 3140 F Measured at 2060, 2780, 2420, and 3140 F	Normal spectral emittance. Induction-heated specimen. Blackbody hole in specimen surface. Thermocouple detector. Monochromator. Temperatures measured with optical pyrometer.	Measured in 1.5 atmosphere of argon. Data taken from curves.



NORMAL TOTAL EMITTANCE OF ZIRCONIUM CARBIDE

NORMAL TOTAL EMITTANCE OF ZIRCONIUM CARBIDE--REFERENCE INFORMATION

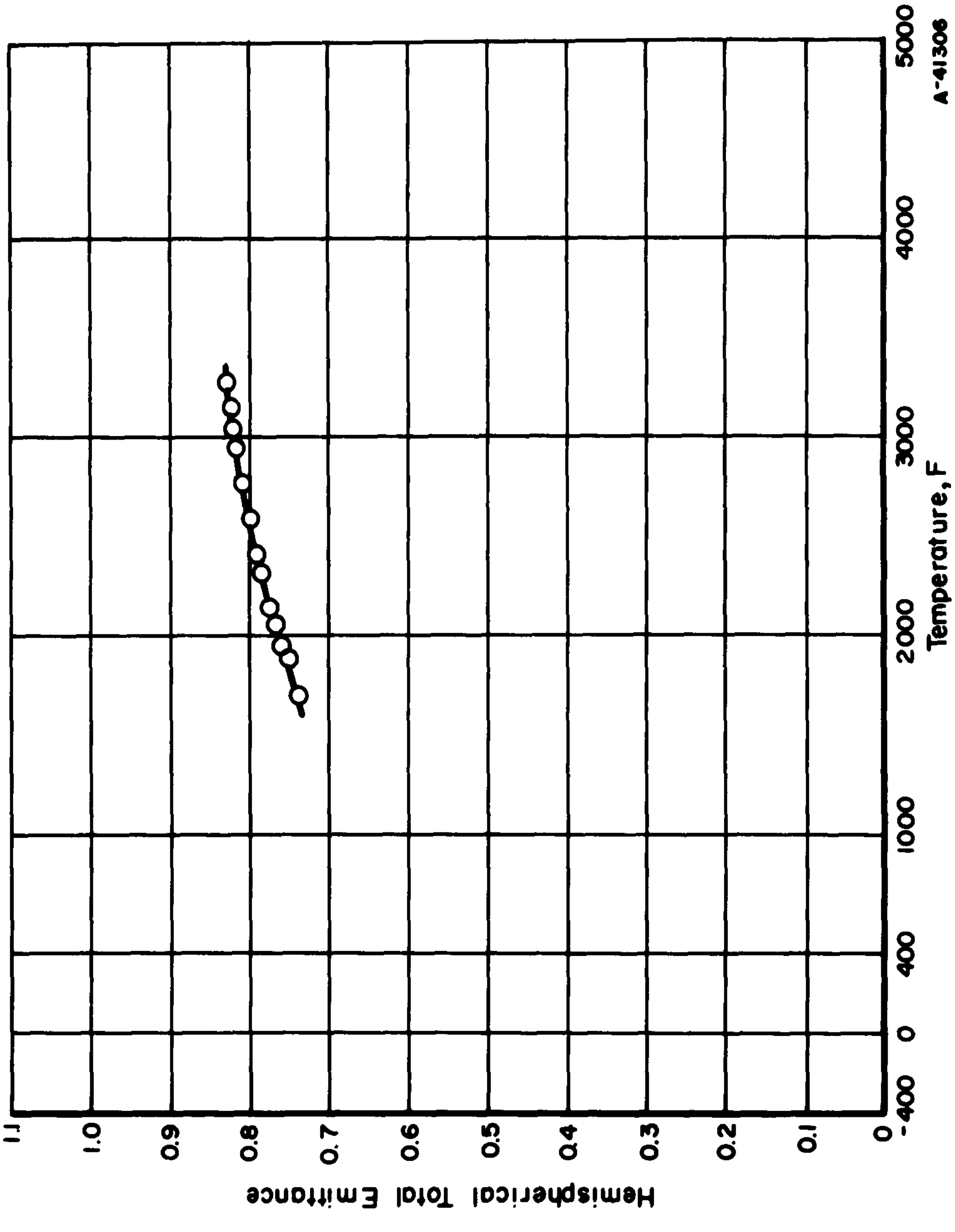
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
5	Coffman, Coulson, and Kibler	O	Formed into "toadstool" shaped specimen Composition and surface condition not given	Normal total emittance. Induction-heated specimen. Comparison blackbody. Temperatures measured with optical pyrometer.	Measured in 1.5 atmosphere of dry, pure, argon. Data taken from curve.



NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM CARBIDE

NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM CARBIDE--REFERENCE INFORMATION

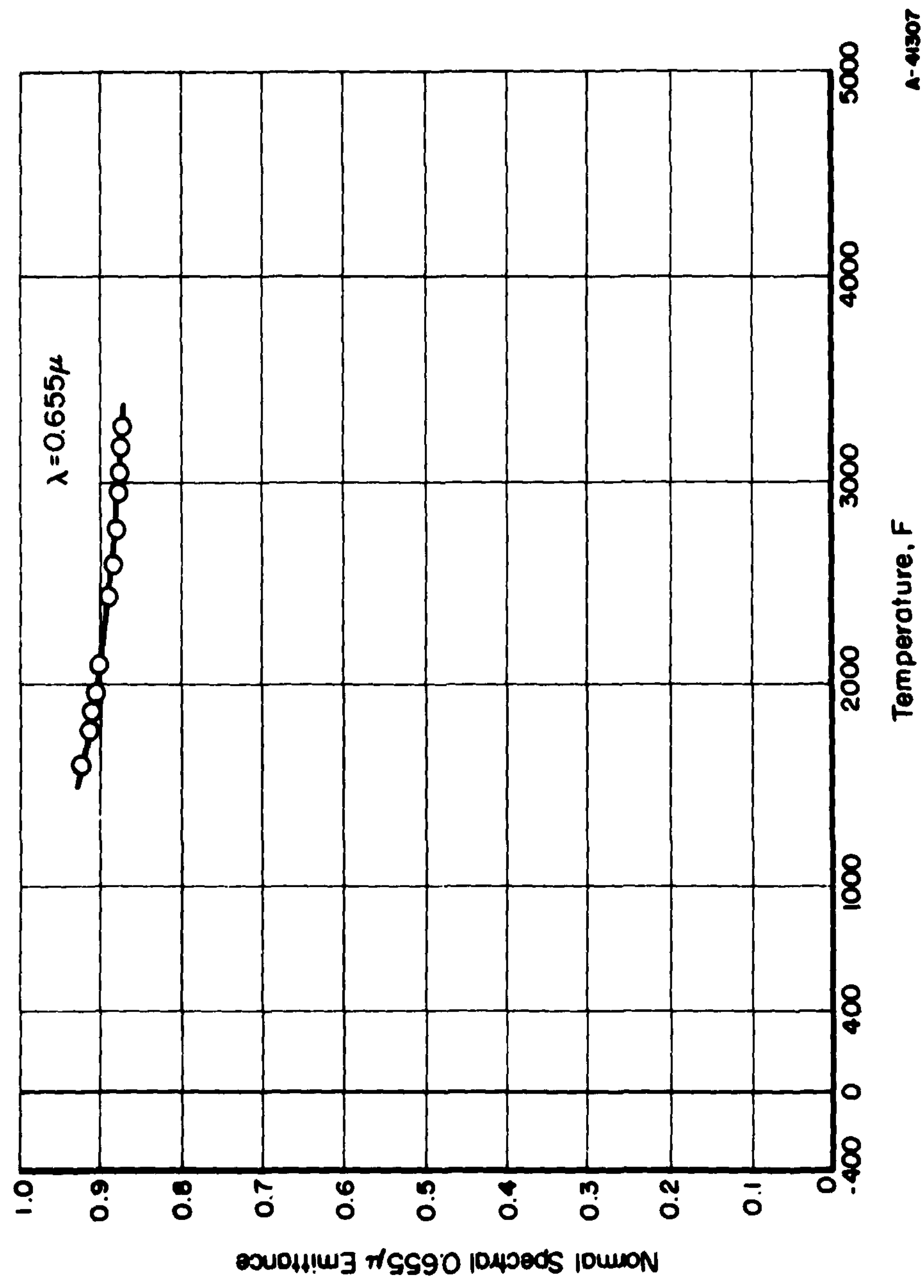
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
6	Riethof		Zirconium carbide Composition or surface condition not given Measured at 3320, 3626, 3990, and 4340 F	Normal spectral emittance. Induction-heated specimen. Blackbody hole in specimen surface. Thermocouple detector. Monochromator. Temperatures measured with optical pyrometer.	Measured in argon. Data taken from curves.



HEMISPHERICAL TOTAL EMITTANCE OF ACHESON GRAPHITE

HEMISPHERICAL TOTAL EMITTANCE OF ACHESON GRAPHITE—REFERENCE INFORMATION

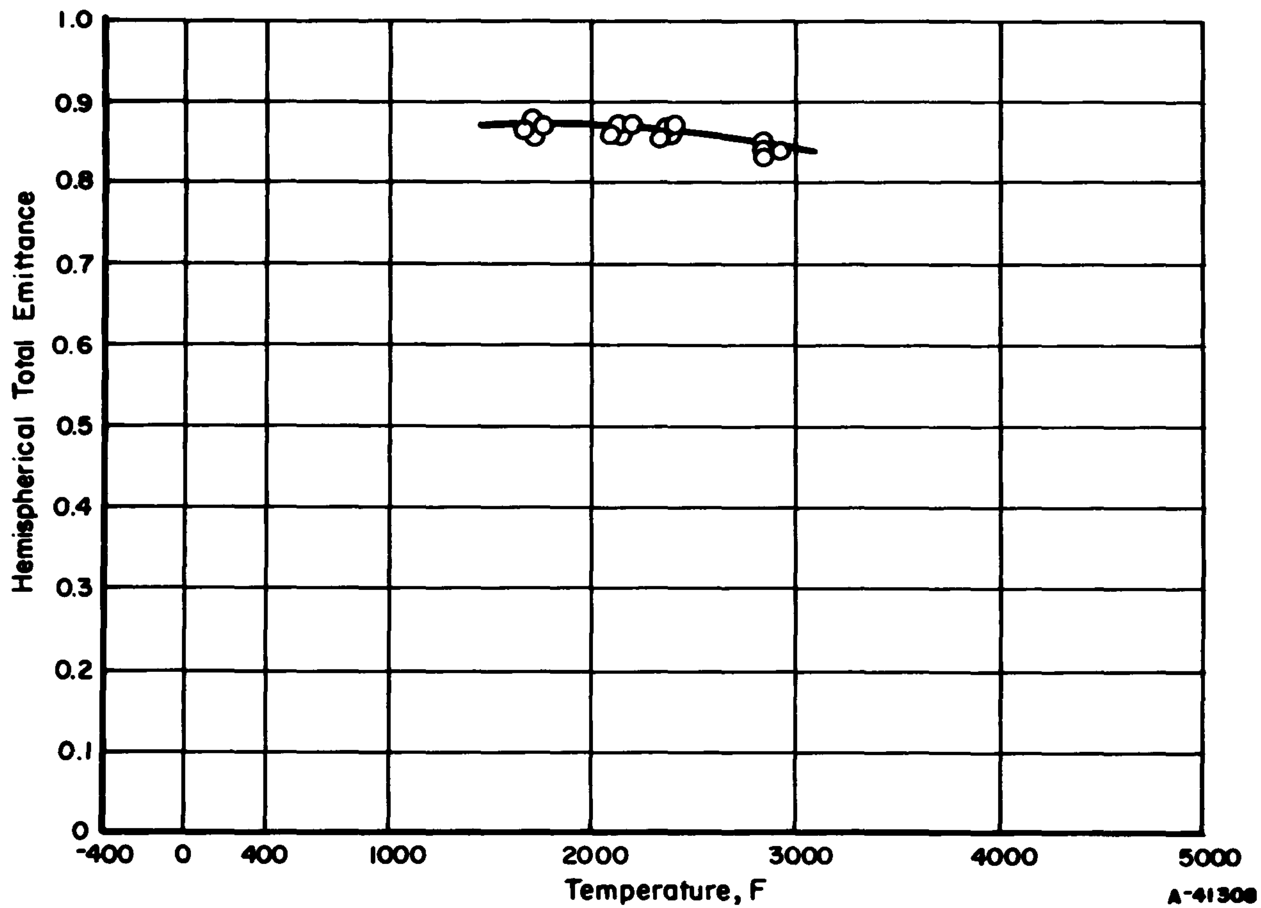
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
9	Jain and Krishnan	O	Acheson graphite Sample held at 2000 K for 1 hour in vacuum, until emittance became steady and reproducible	Hemispherical total emittance. Hole-in-tube method. Correction of inside blackbody temperature to surface temperature made using known thermal conductivity and wall thickness. Blackbody temperature measured with optical pyrometer.	Measured in vacuum. Data taken from curves.



NORMAL SPECTRAL EMITTANCE OF ACHESON GRAPHITE

NORMAL SPECTRAL EMITTANCE OF ACHESON GRAPHITE--REFERENCE INFORMATION

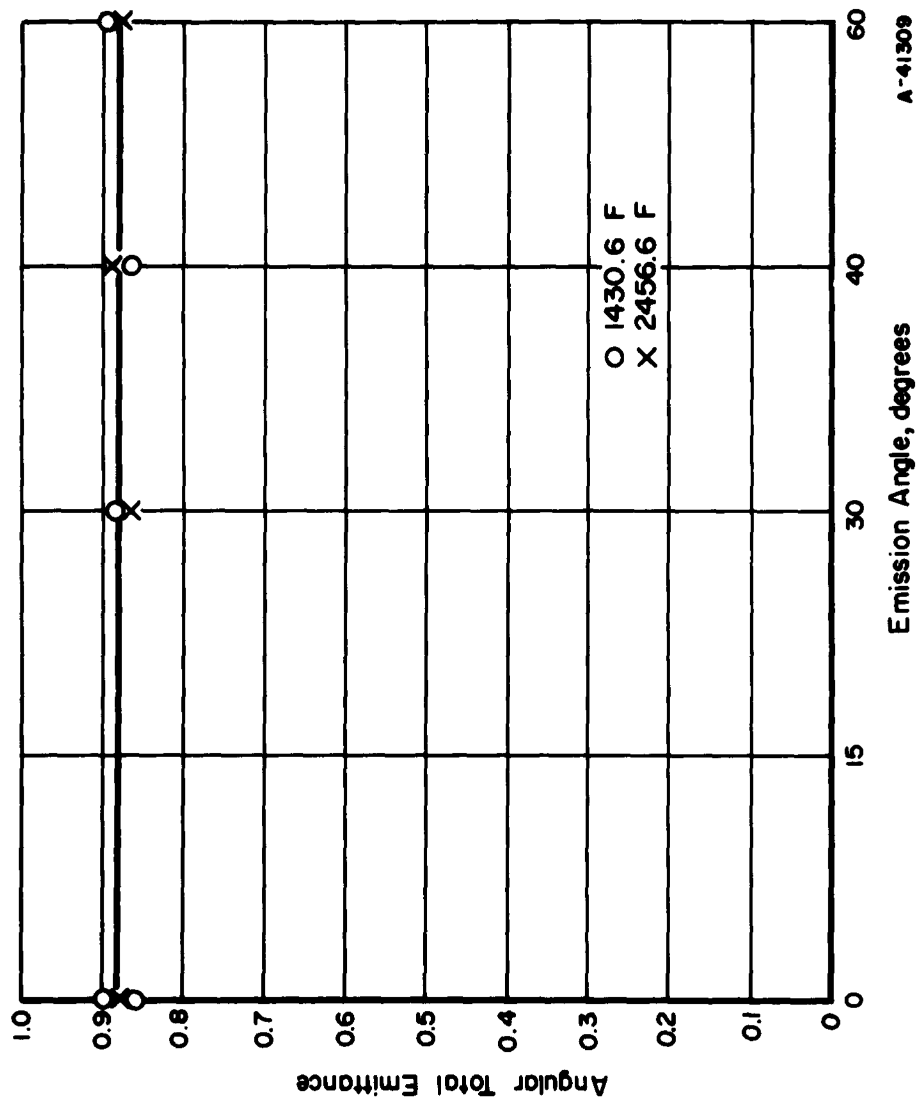
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
9	Jain and Krishnan	O	Acheson graphite Specimen held at 2000 K for 1 hour in vacuum until emittance became steady and reproducible	Normal spectral emittance. Hole-in-tube method. Temperatures measured with optical pyrometer.	Measured in vacuum. Data taken from curves. ($\lambda = 0.665\mu$)



HEMISPHERICAL TOTAL EMITTANCE OF ATJ GRAPHITE

HEMISPHERICAL TOTAL EMITTANCE OF ATJ GRAPHITE—REFERENCE INFORMATION

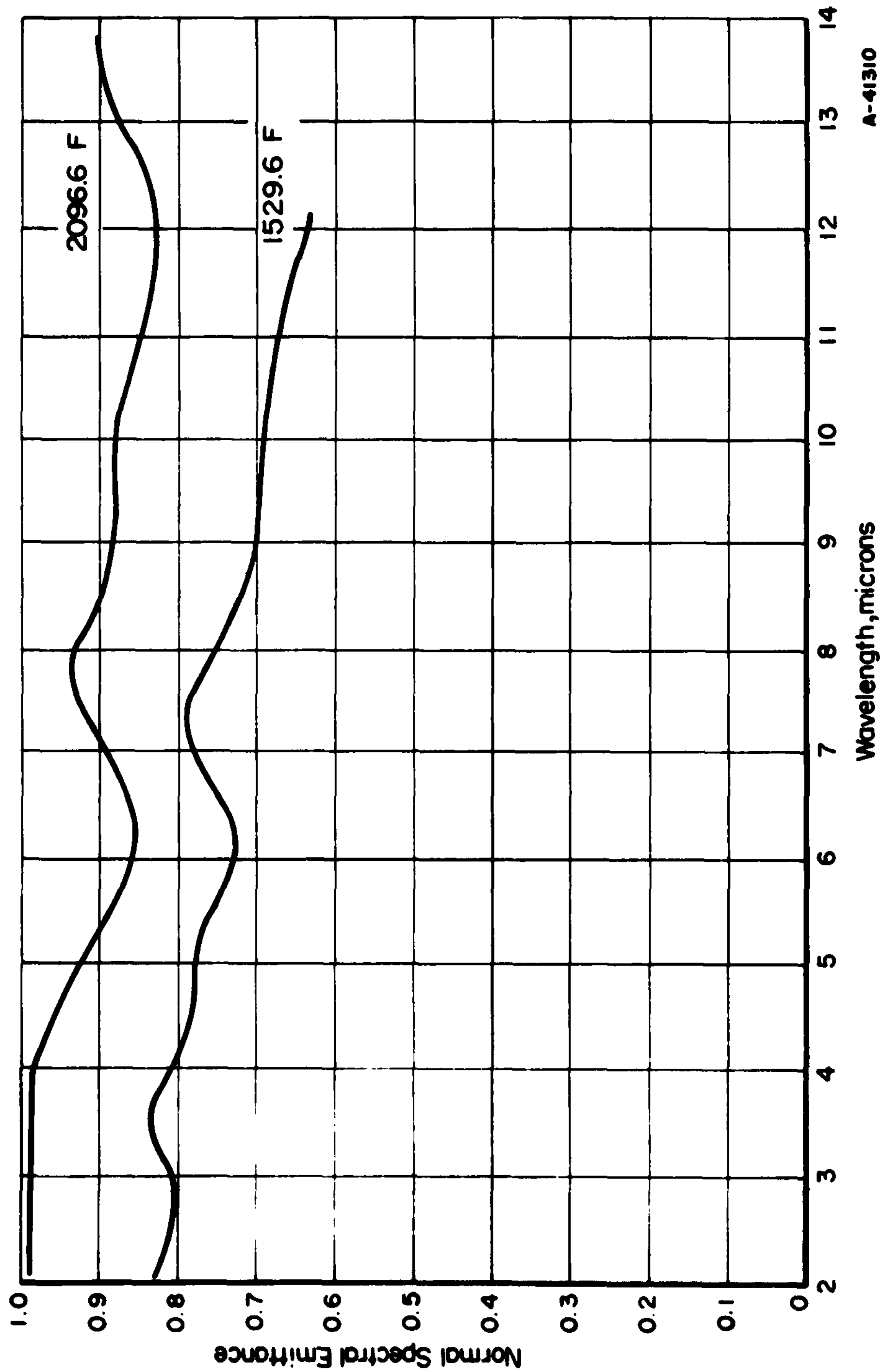
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
4	Blau, Chaffee, Jasperse, and Martin	O	ATJ graphite Surface condition not given	Normal total emittance. (Hemispherical emittance equals normal emittance for this specimen.) Induction-heated specimen. Monochromator with prism replaced by plane mirror. Thermocouple detector. Blackbody hole drilled in specimen surface. Temperatures measured with micro-optical pyrometer.	Measured in 90% argon - 10% hydrogen atmosphere. Data taken from curves.



TOTAL EMITTANCE VERSUS EMISSION ANGLE OF ATJ GRAPHITE

TOTAL EMITTANCE VERSUS EMISSION ANGLE OF ATJ GRAPHITE--REFERENCE INFORMATION

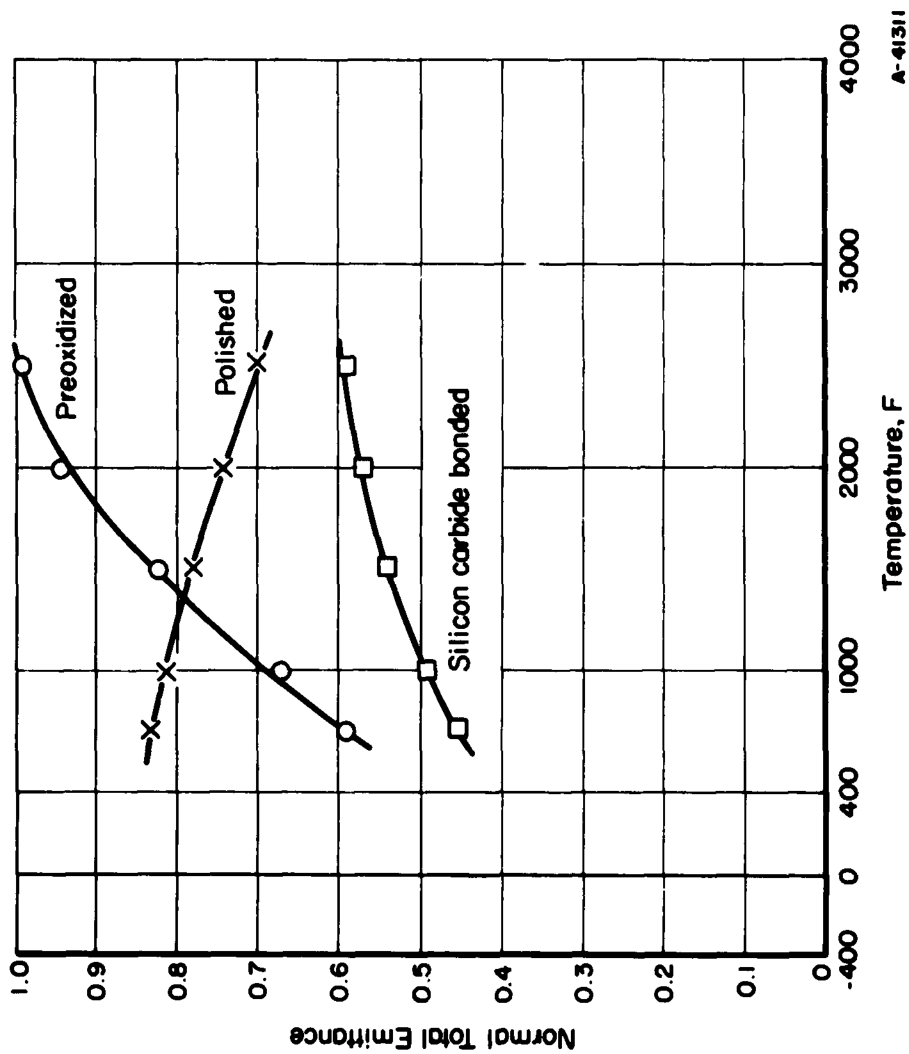
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
4	Blau, Chaffee, Jasperse, and Martin		ATJ graphite Surface smooth and flat, but not polished.	Total emittance measured normally and at 30, 45, and 60 degrees from the normal. Induction-heated specimen. Monochromator with prism replaced by plane mirror. Thermocouple detector. Blackbody hole drilled in specimen surface. Temperatures measured with micro-optical pyrometer.	Measured in 90% argon - 10% hydrogen atmosphere. Data taken from curves. Normal emittance equals hemispherical emittance for this specimen.
		O	Measured at 1431 F		
		X	Measured at 2457 F		



NORMAL SPECTRAL EMITTANCE OF ATJ GRAPHITE

NORMAL SPECTRAL EMITTANCE OF ATJ GRAPHITE—REFERENCE INFORMATION

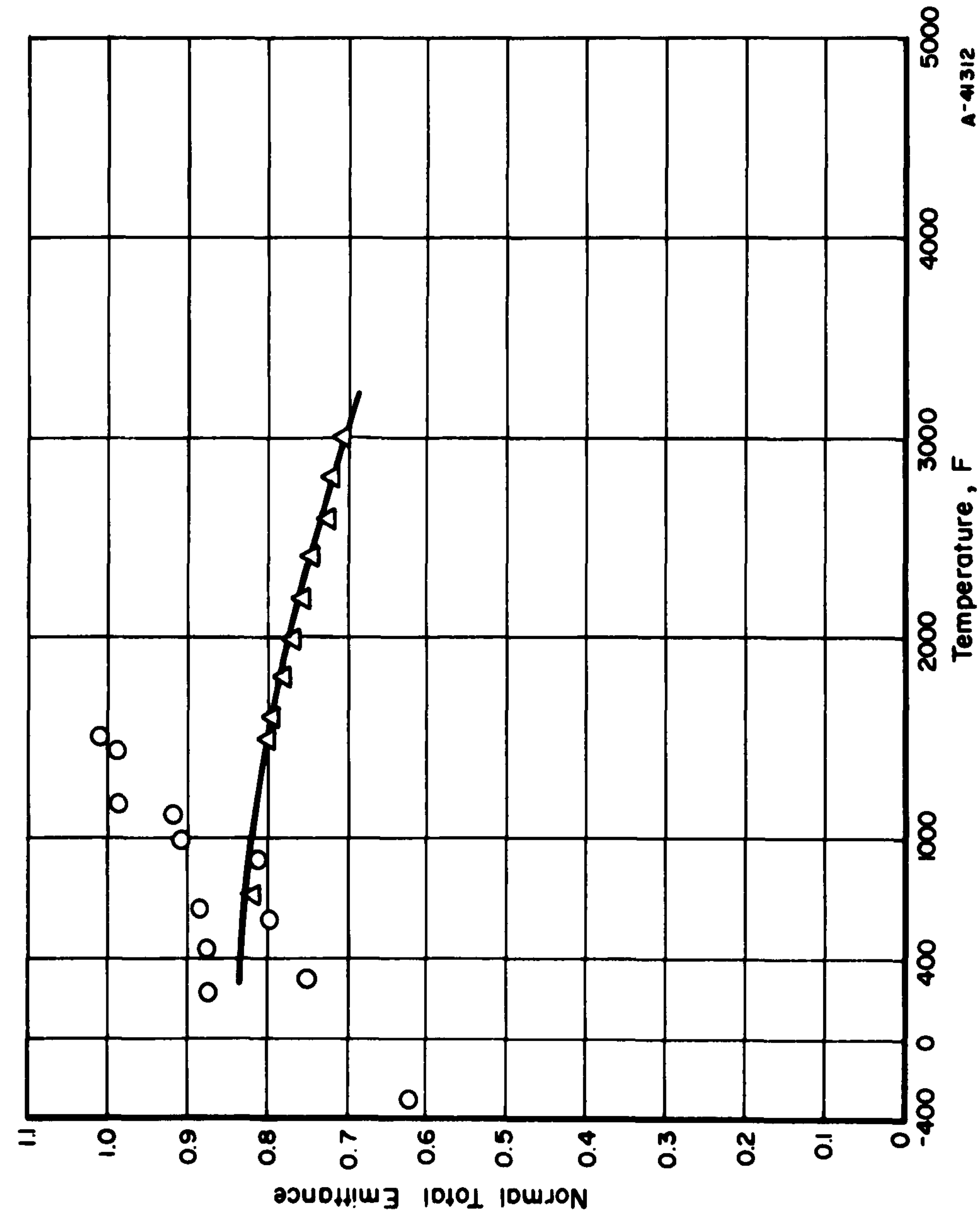
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
4	Blau, Chaffee, Jasperse, and Martin		ATJ graphite Surface smooth and flat but not polished	Normal spectral emittance. Induction-heated specimen. Monochromator and thermocouple detector. Blackbody hole drilled in specimen surface. Temperatures measured with micro-optical pyrometer.	Measured in 90% argon - 10% hydrogen atmosphere. Data taken from curves.



NORMAL TOTAL EMITTANCE OF ELECTRODE GRAPHITE

NORMAL TOTAL EMITTANCE OF ELECTRODE GRAPHITE--REFERENCE INFORMATION

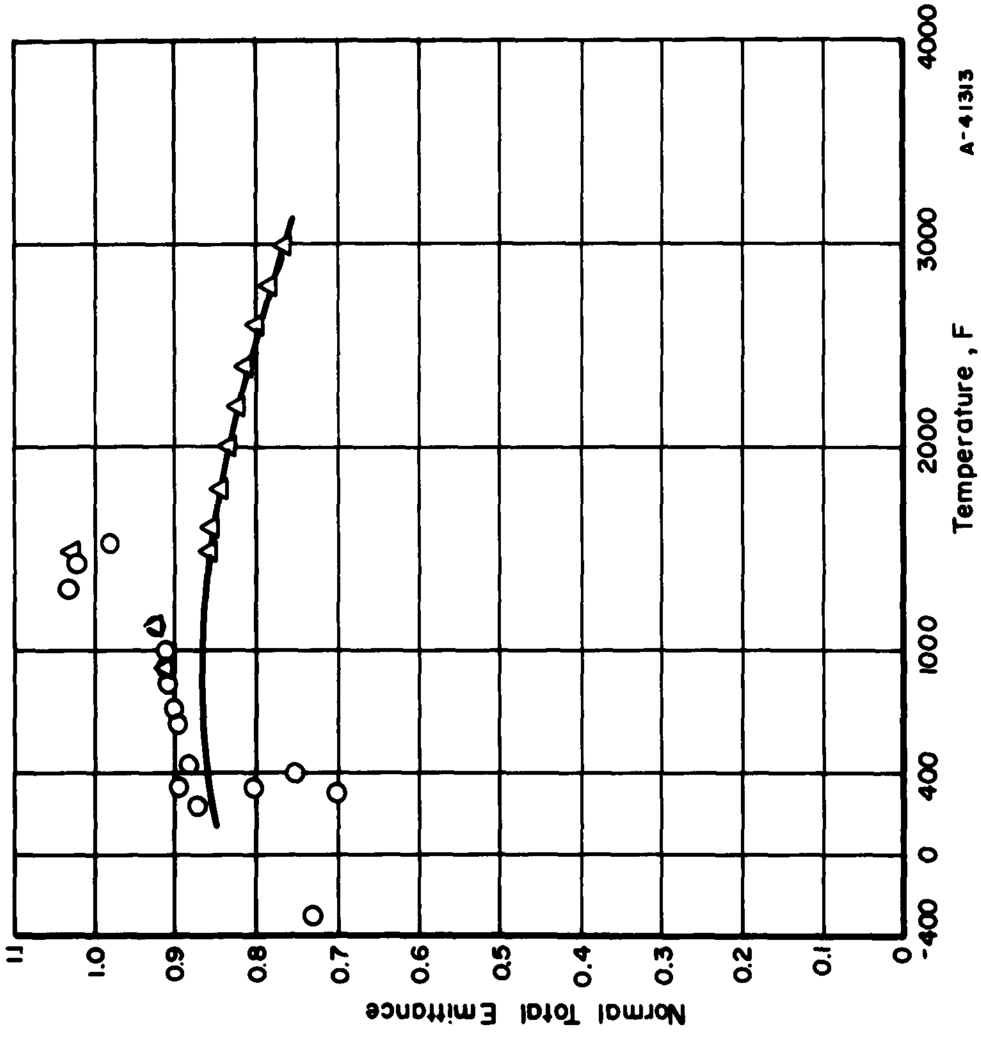
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
1	Anthony and Pearl		Electrode graphite	Normal total emittance. Induction-heated specimen. Comparison blackbody. Thermopile detector. Temperatures measured with thermocouples.	Measured in purge of helium gas. Data taken from table.
		○	Preoxidized		
		×	Polished		
		□	Silicon carbide bonded		



NORMAL TOTAL EMITTANCE OF GBE GRAPHITE

NORMAL TOTAL EMITTANCE OF GBE GRAPHITE—REFERENCE INFORMATION

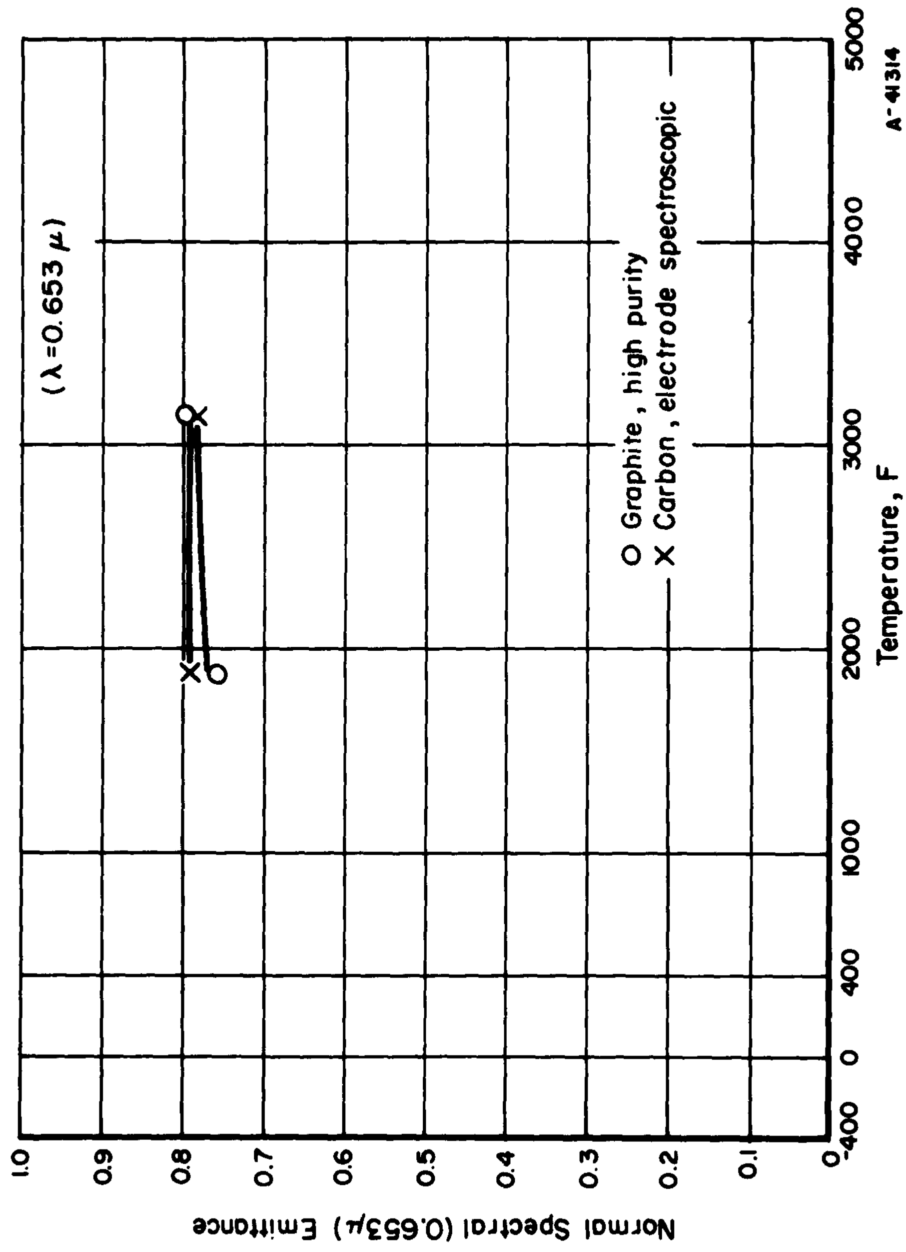
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
8	Olson and Morris	○	National GBE graphite Surface condition not given	Normal total emittance. Resistance-heated strip specimen. Comparison blackbody. Temperatures measured with thermocouples. Thermistor detector.	Measured in vacuum. Data taken from curves.
7	Betz, Olson, Schurin, and Morris	△	Same as above	Same as above.	Same as above.



NORMAL TOTAL EMITTANCE OF TYPE GBH GRAPHITE

NORMAL TOTAL EMITTANCE OF TYPE GBH GRAPHITE--REFERENCE INFORMATION

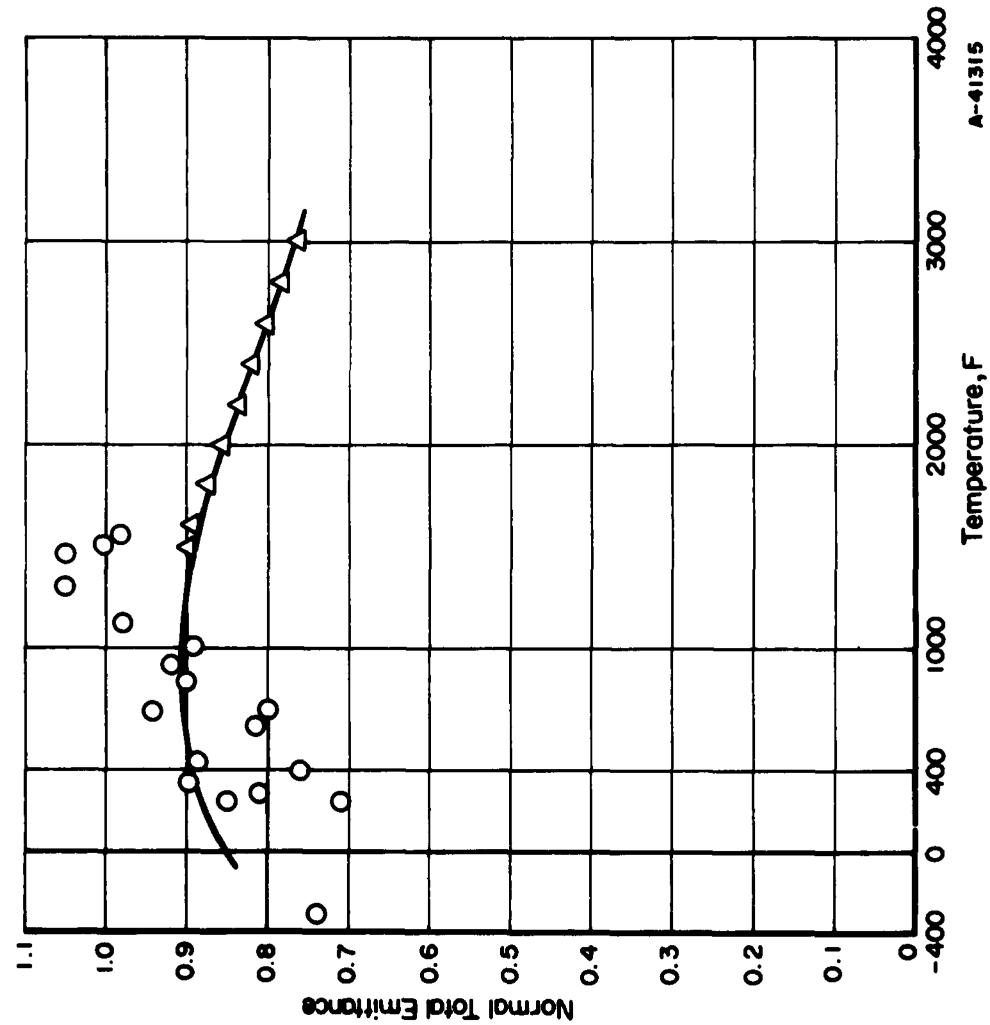
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
8	Olson and Morris	○	National GBH graphite Surface condition not given Note: Changed with cycling	Normal total emittance. Resistance-heated strip specimen. Comparison blackbody. Thermistor detector. Temperatures measured with thermocouples.	Measured in vacuum. Data taken from curves.
7	Betz, Olson, Schurin, and Morris	△	Surface condition not given	Same as above.	Measured in vacuum. Data taken from table.



NORMAL SPECTRAL EMITTANCE OF GRAPHITE AND CARBON

NORMAL SPECTRAL EMITTANCE OF GRAPHITE AND CARBON—REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
10	Thorn and Simpson	O	High-purity, medium-density graphite	Normal spectral emittance. Modified hole-in-tube method.	Measured in vacuum. Data taken from curves.
		X	Spectroscopic electrode carbon	Temperatures measured with calibrated optical pyrometer.	($\lambda = 0.653\mu$)
			Surface condition, polished and then heated to 1800 K in vacuum for 3 hours		



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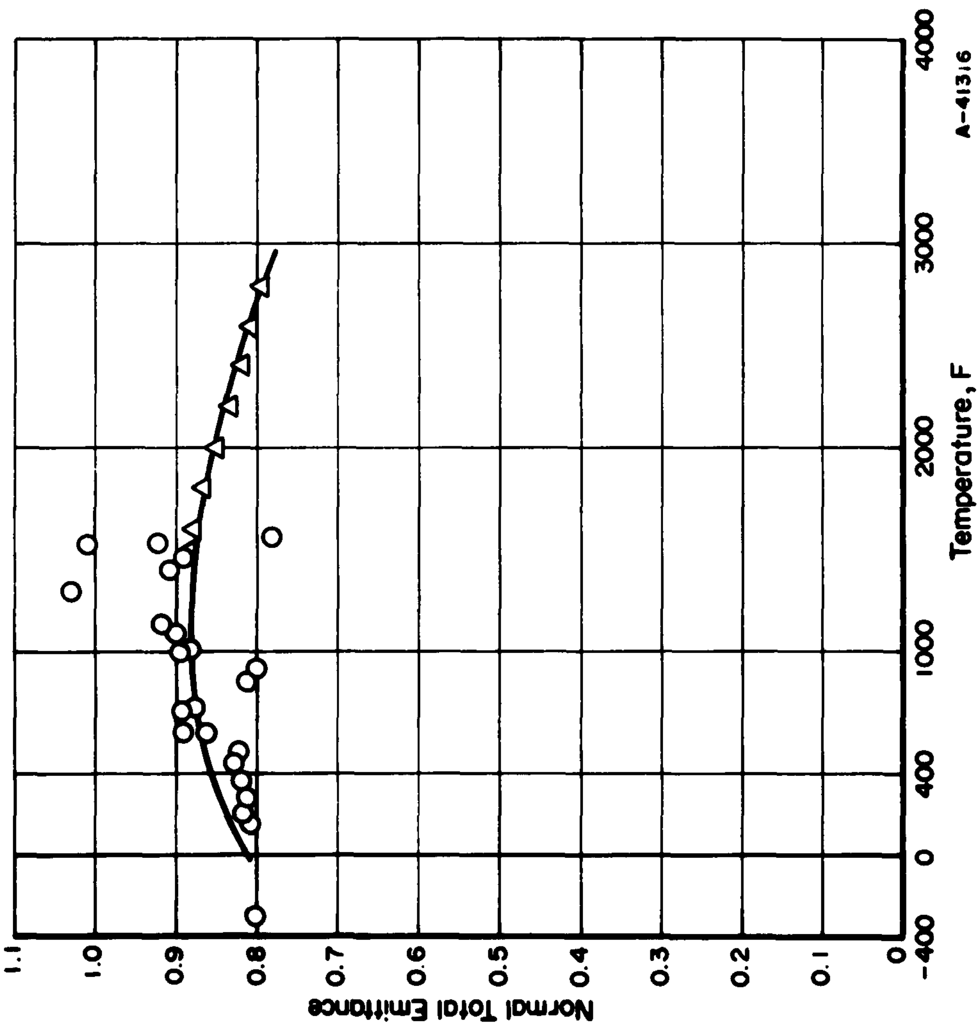
NORMAL TOTAL EMITTANCE OF TYPE 3474D GRAPHITE

NORMAL TOTAL EMITTANCE OF TYPE 3474D GRAPHITE--REFERENCE INFORMATION

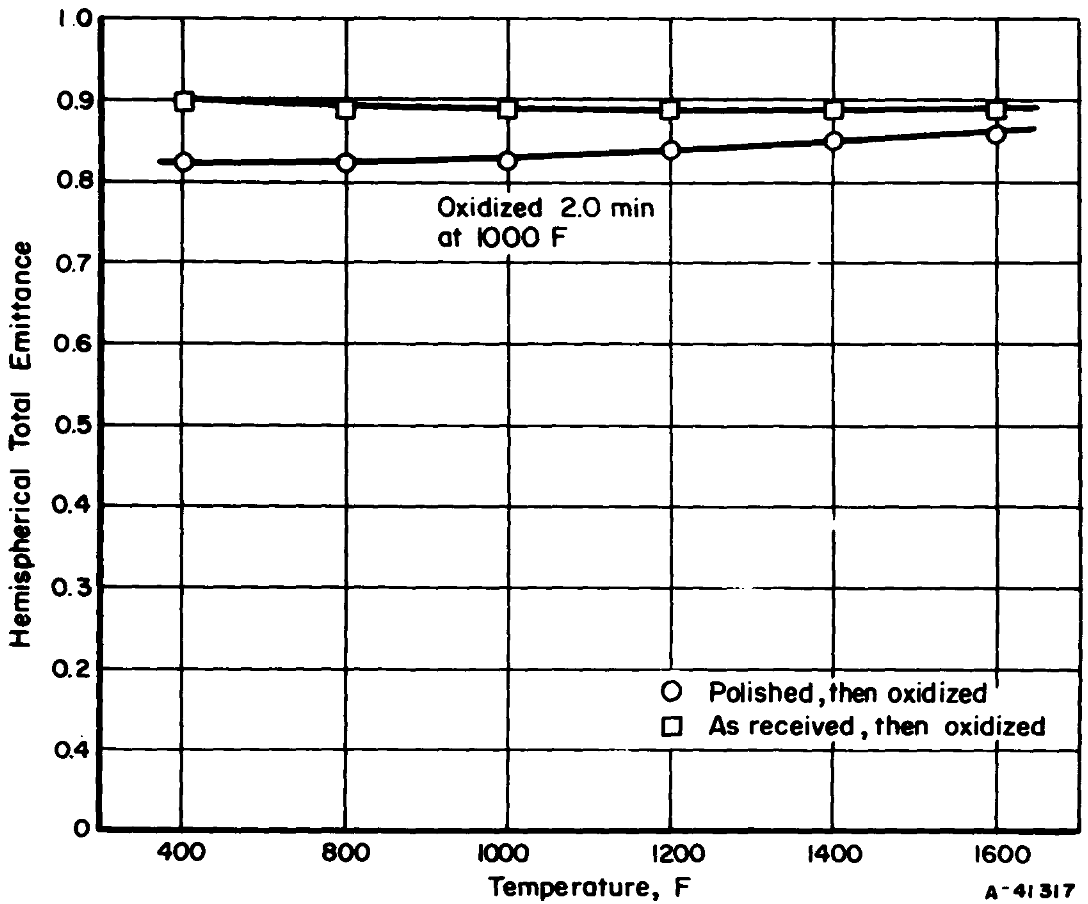
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
8	Olson and Morris	○	Speer 3474D graphite Surface condition not given Note: Changed with cycling	Normal total emittance. Resistance-heated strip specimen. Comparison blackbody. Thermistor detector. Temperatures measured with thermocouples.	Measured in vacuum. Data taken from curves.
7	Betz, Olson, Schurin, and Morris	△	Surface condition not given	Same as above.	Measured in vacuum. Data taken from table.



NORMAL TOTAL EMITTANCE OF TYPE 7087 GRAPHITE

NORMAL TOTAL EMITTANCE OF TYPE 7087 GRAPHITE--REFERENCE INFORMATION

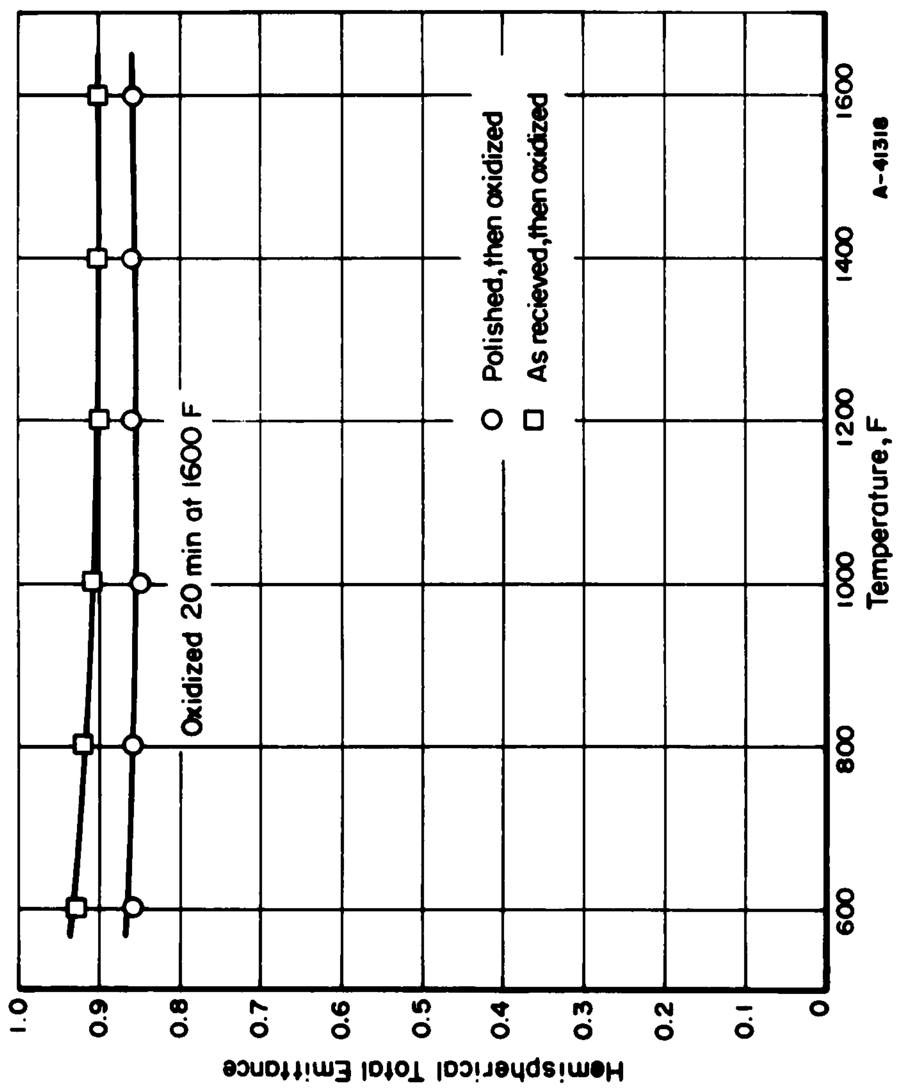
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
8	Olson and Morris	○	Speer 7087 graphite Surface condition not given Note: Changed with cycling	Normal total emittance. Resistance-heated strip specimen. Comparison blackbody. Thermistor detector. Temperatures measured with thermocouples.	Measured in vacuum. Data taken from curves.
7	Betz, Olson, Schurin, and Morris	△	Surface condition not given	Same as above.	Measured in vacuum. Data taken from table.



HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K150A Ni-TiC HARD METAL

HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K150A Ni-TiC HARD METAL--REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
11	Wade and Casey		Composition: 10Ni, 80TiC, 10CbC	Hemispherical total emittance. (Total emittance measured normally and at various angles. Normal emittance equals hemispherical emittance.) Thermopile total ratiation detector. Resistance-heated specimen. Comparison blackbody. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.
		□	As received, then oxidized		
		○	Polished: Hand lapped with 3 micron and 1 micron diamond paste, then oxidized		

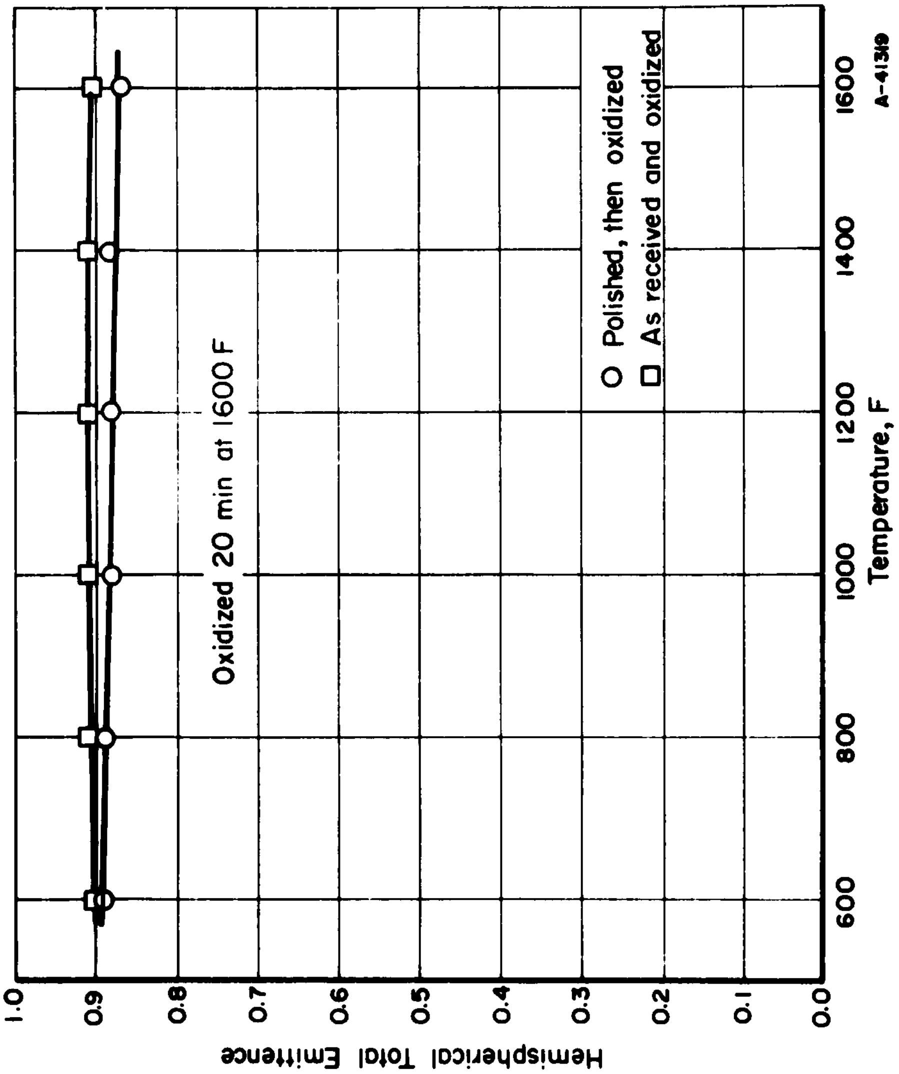


HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K151A Ni-TiC HARD METAL

HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K151A Ni-TiC HARD METAL—REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
11	Wade and Casey		Composition: 20Ni, 70TiC, 10CbC	Hemispherical total emittance. (Total emittance measured normally and at various angles. Normal emittance equals hemispherical emittance.) Thermopile total radiation detector. Resistance-heated specimen. Comparison blackbody. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.
		□	As received, then oxidized		
		○	Polished; hand lapped with 3-micron and 1-micron diamond paste, then oxidized		

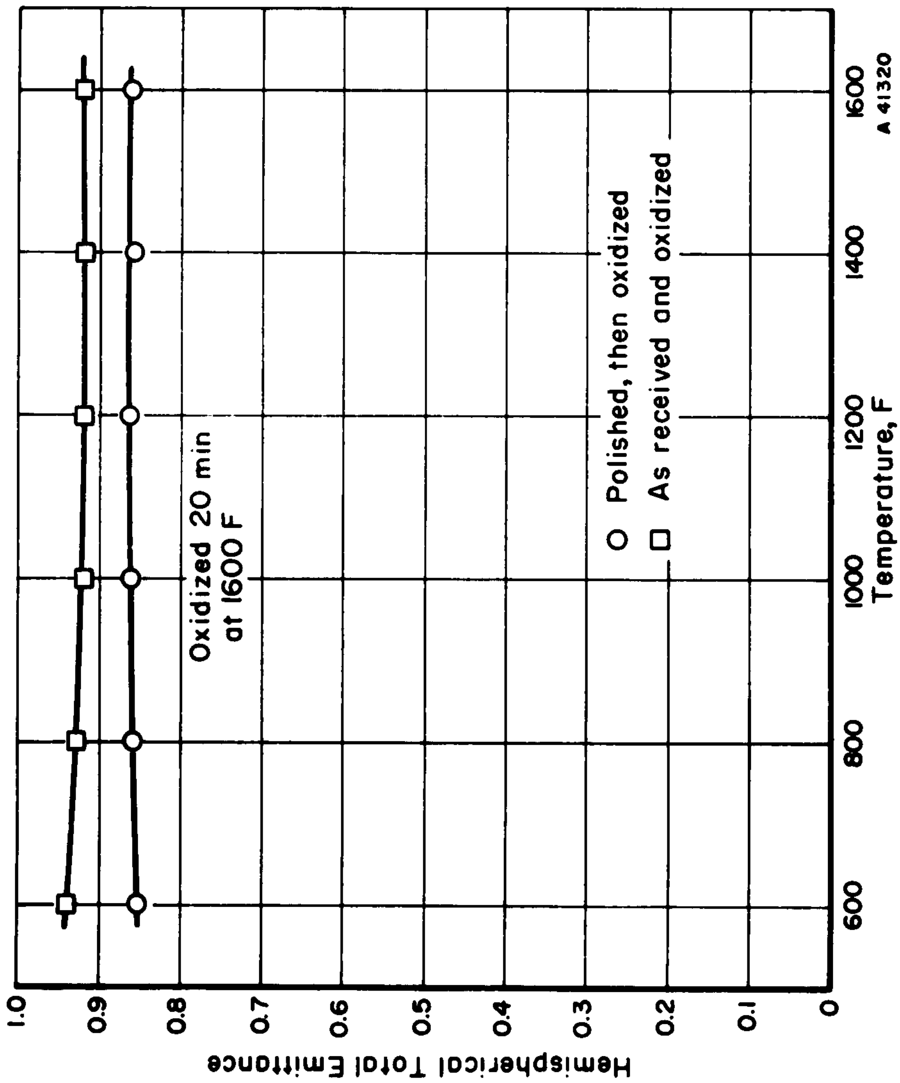
Composition: 20Ni, 70TiC, 10CbC



HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K152B Ni-TiC HARD METAL

HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K152B Ni-TiC HARD METAL--REFERENCE INFORMATION

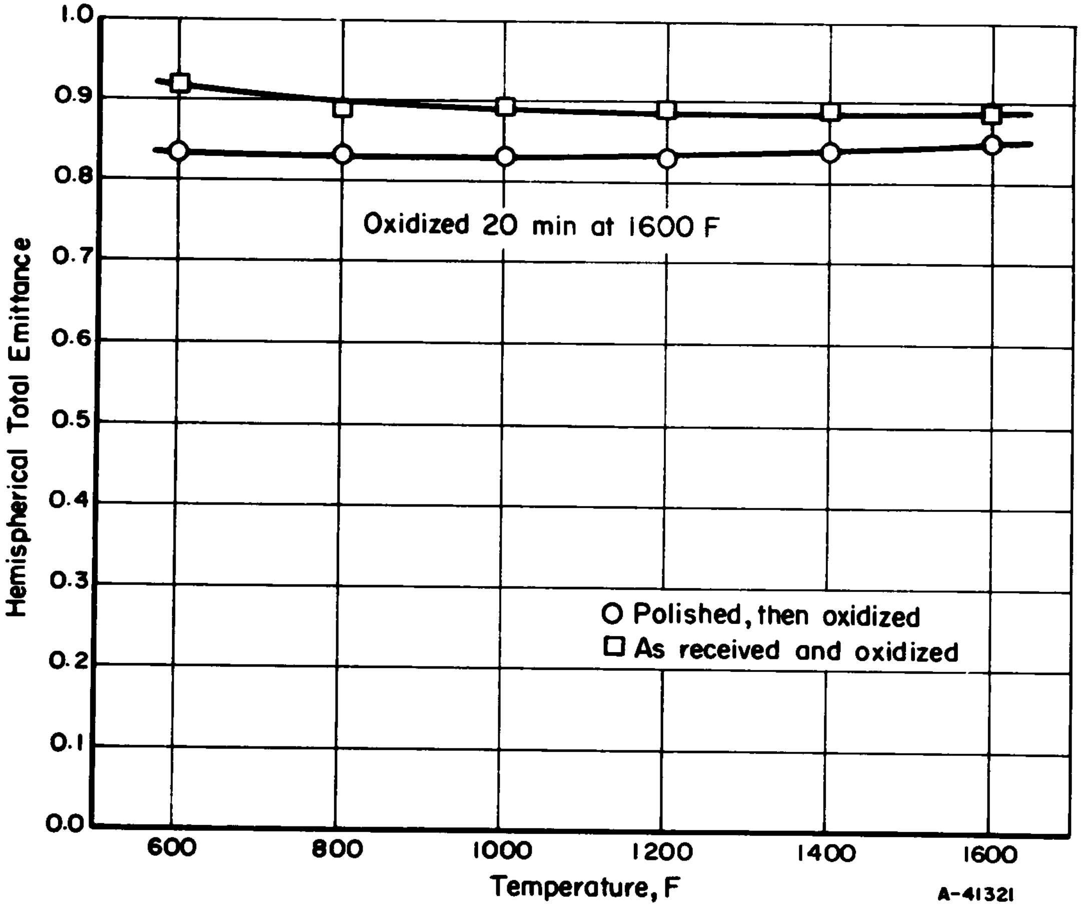
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
11	Wade and Casey		Composition: 30Ni, 65TiC, 5CbC	Hemispherical total emittance. (Total emittance measured normally and at various angles. Normal emittance equals hemispherical emittance.) Thermopile total radiation detector. Resistance-heated specimen. Comparison blackbody. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.
		□	As received, then oxidized		
		○	Polished; hand lapped with 3-micron and 1-micron diamond paste, then oxidized		



HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K153B Ni-TiC HARD METAL

HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K153B Ni-TiC HARD METAL--REFERENCE INFORMATION

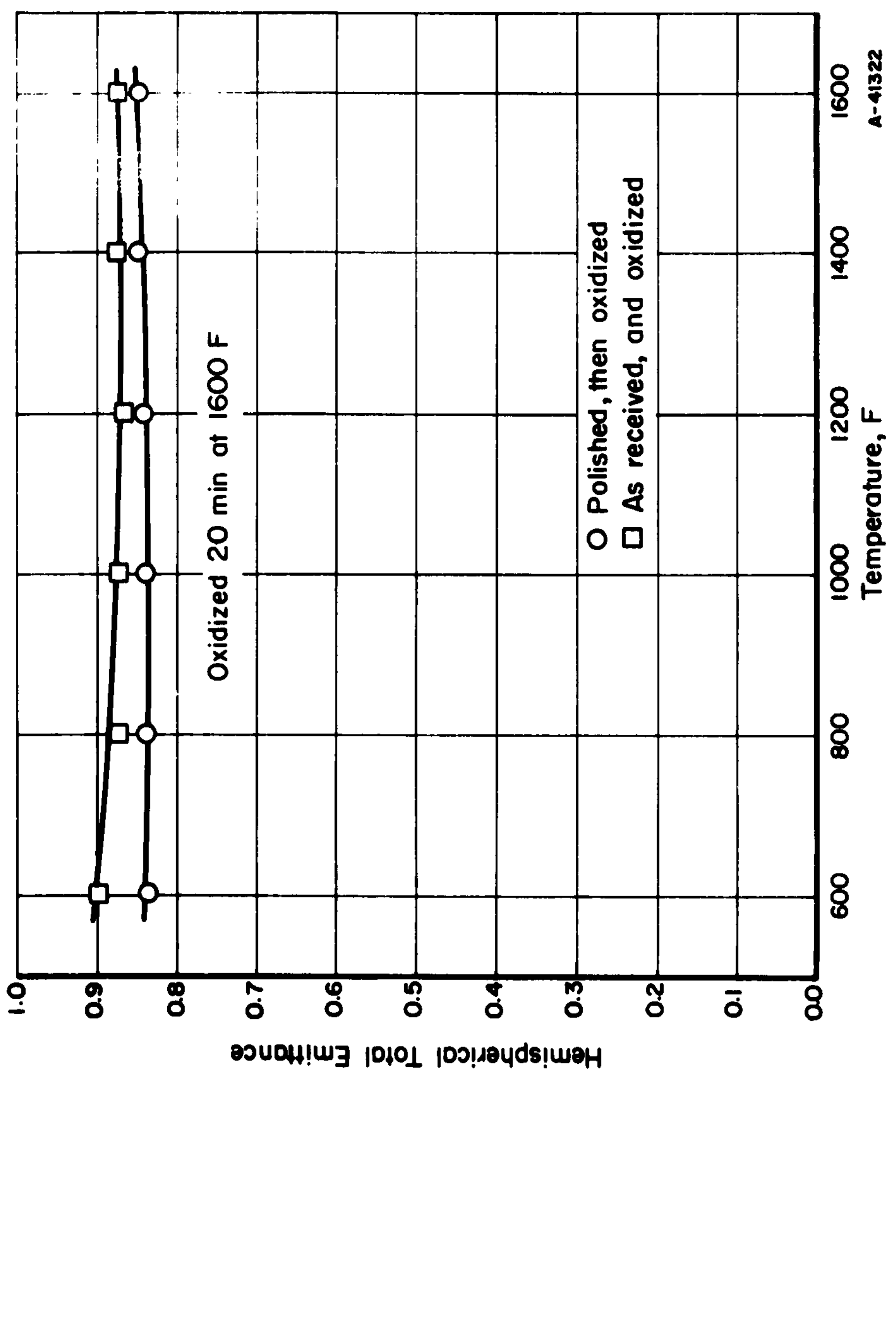
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
11	Wade and Casey		Composition: 40Ni, 54TiC, 6CbC	Hemispherical total emittance. (Total emittance measured normally and at various angles. Normal emittance equals hemispherical emittance.) Thermopile total radiation detector. Resistance-heated specimen. Comparison blackbody. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.
		□	As received, then oxidized 20 minutes at 1600 F		
		○	Polished; lapped with 3-micron and 1-micron diamond paste, then oxidized 20 minutes at 1600 F		



HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K163B1 Ni-TiC HARD METAL

HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K163B1 Ni-TiC HARD METAL--REFERENCE INFORMATION

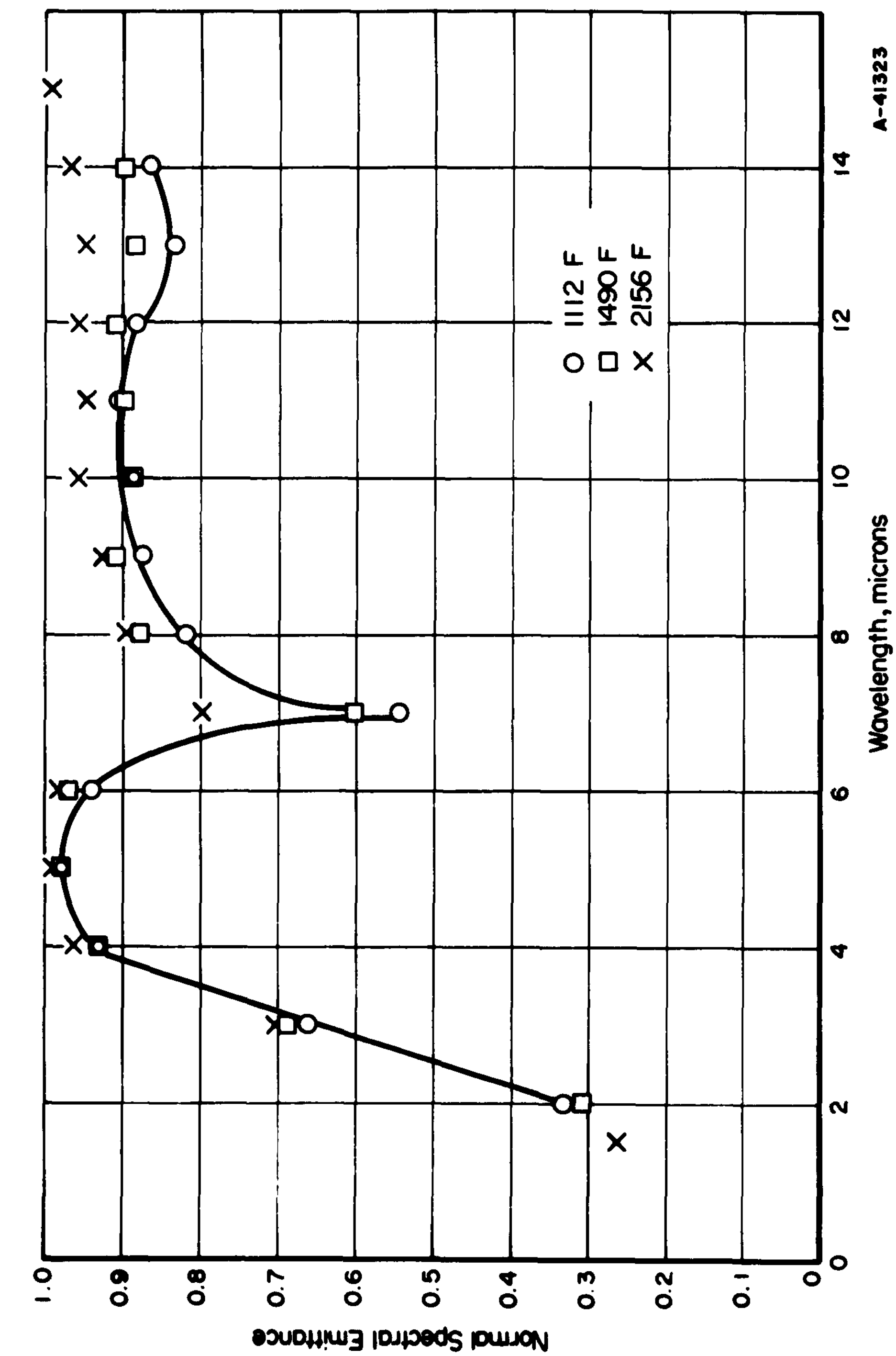
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
11	Wade and Casey		Composition: 33.3Ni, 54TiC, 6.7Mo, 6CbC	Hemispherical total emittance. (Total emittance measured normally and at various angles. Normal emittance equals hemispherical emittance.) Thermopile total radiation detector. Resistance-heated specimen. Comparison blackbody. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.
		□	As received, then oxidized 20 minutes at 1600 F		
		○	Polished; lapped with 3-micron and 1-micron diamond paste, then oxidized 20 minutes at 1600 F		



HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K184B Ni-TiC HARD METAL

HEMISPHERICAL TOTAL EMITTANCE OF OXIDIZED K184B Ni-TiC HARD METAL--REFERENCE INFORMATION

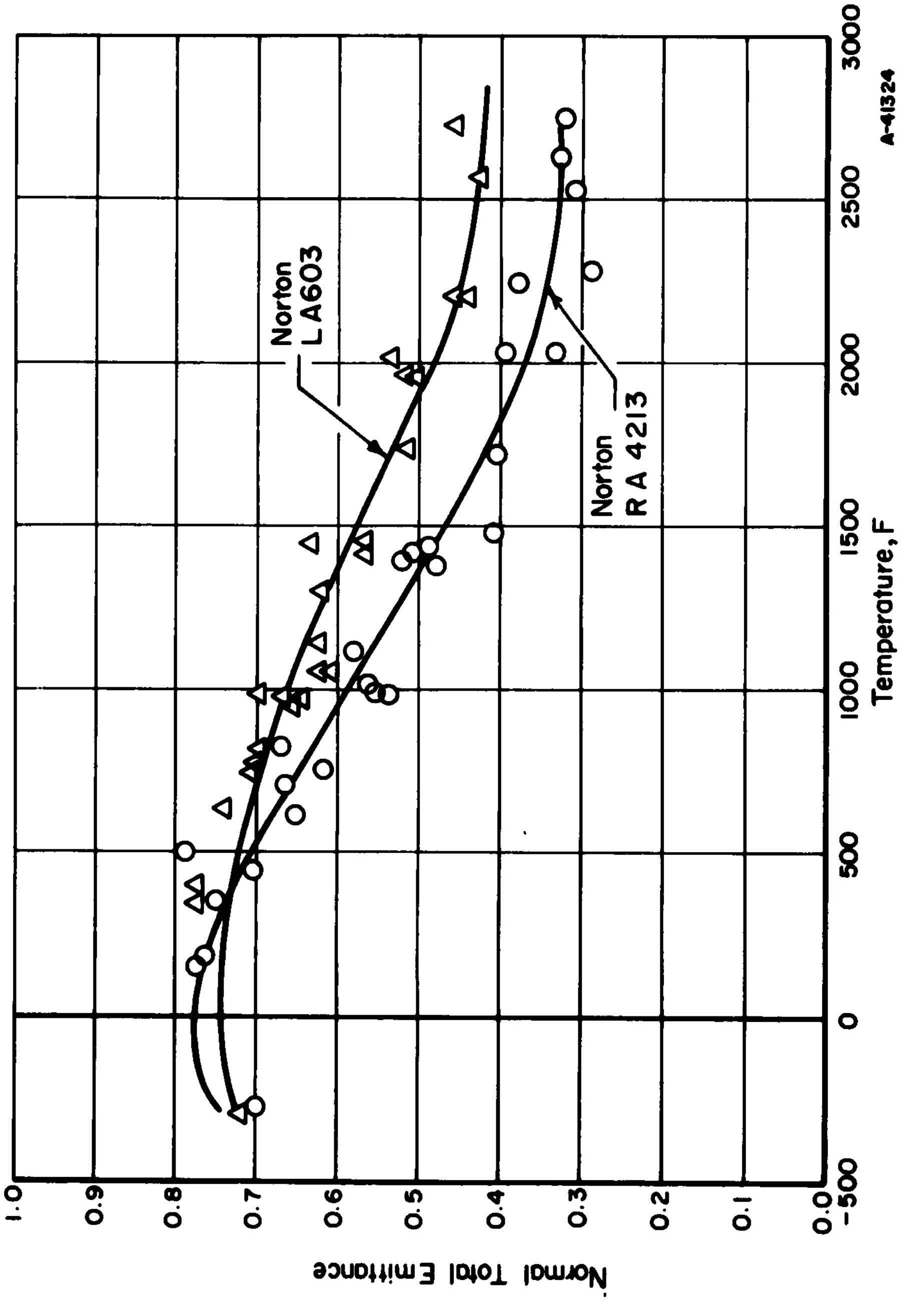
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
11	Wade and Casey		Composition: 40Ni, 40TiC, 10CbC, 4Mo, 3Al, 3Cr	Hemispherical total emittance. (Total emittance measured normally and at various angles. Normal emittance equals hemispherical emittance.) Thermopile total radiation detector. Resistance-heated specimen. Comparison blackbody. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.
		□	As received, then oxidized 20 minutes at 1600 F		
		○	Polished; lapped with 3-micron and 1-micron diamond paste, then oxidized 20 minutes at 1600 F		



NORMAL SPECTRAL EMITTANCE OF BORON NITRIDE

NORMAL SPECTRAL EMITTANCE OF BORON NITRIDE--REFERENCE INFORMATION

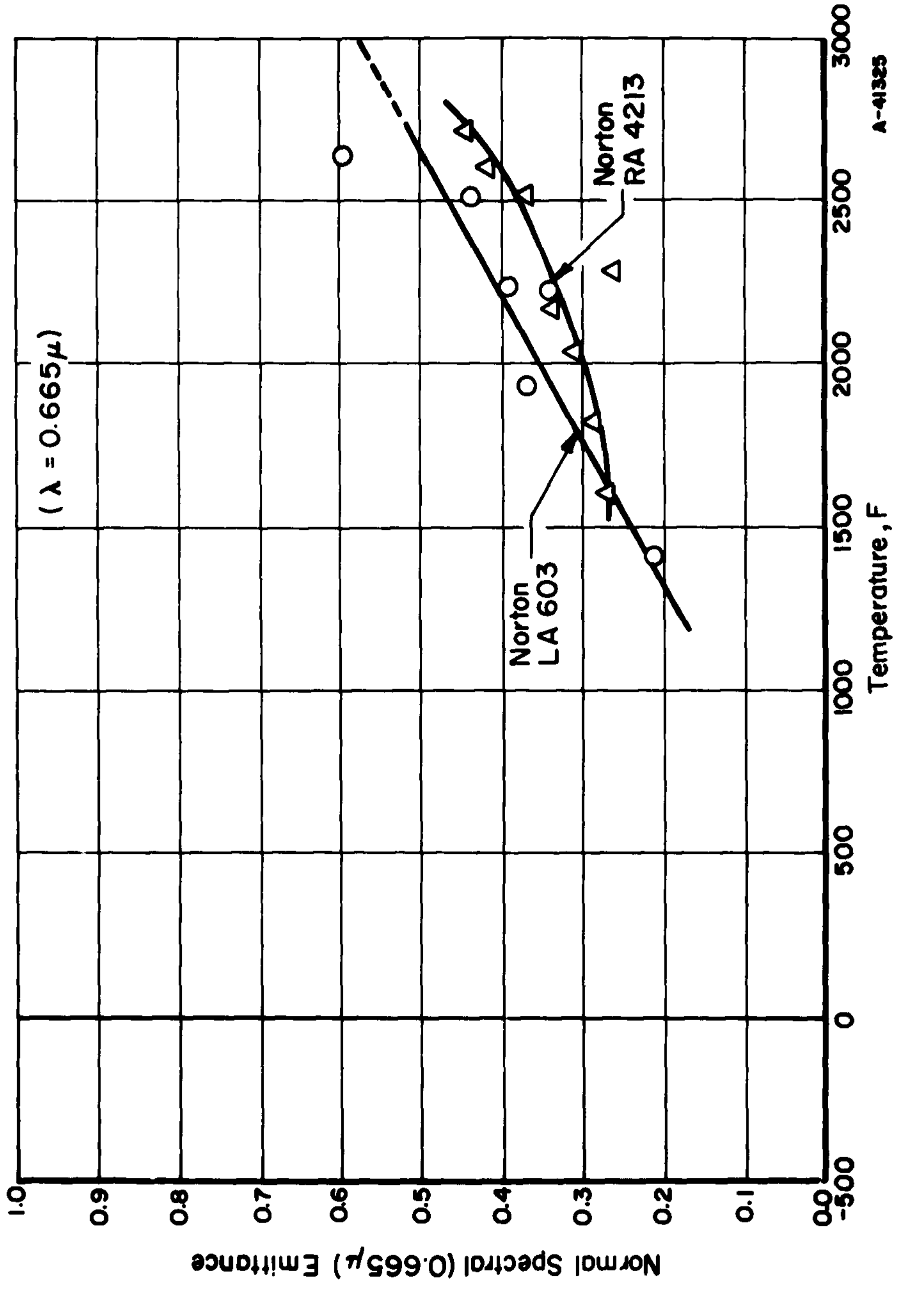
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
3	Blau, Marsh, Martin, Jasperse, and Chaffee		Boron nitride Purity and surface condition not given	Normal spectral emittance. Specimen mounted in wall of cylindrical Globar (SiC) heater. Comparison blackbody hole in heater wall. Monochromator and thermocouple detector. Temperatures measured with thermocouples.	Measured in air. Data taken from curves. (Curve drawn through 1112 F points only.)
		○	Measured at 1112 F		
		□	Measured at 1490 F		
		×	Measured at 2156 F		



NORMAL TOTAL EMITTANCE OF ALUMINUM OXIDE

NORMAL TOTAL EMITTANCE OF ALUMINUM OXIDE--REFERENCE INFORMATION

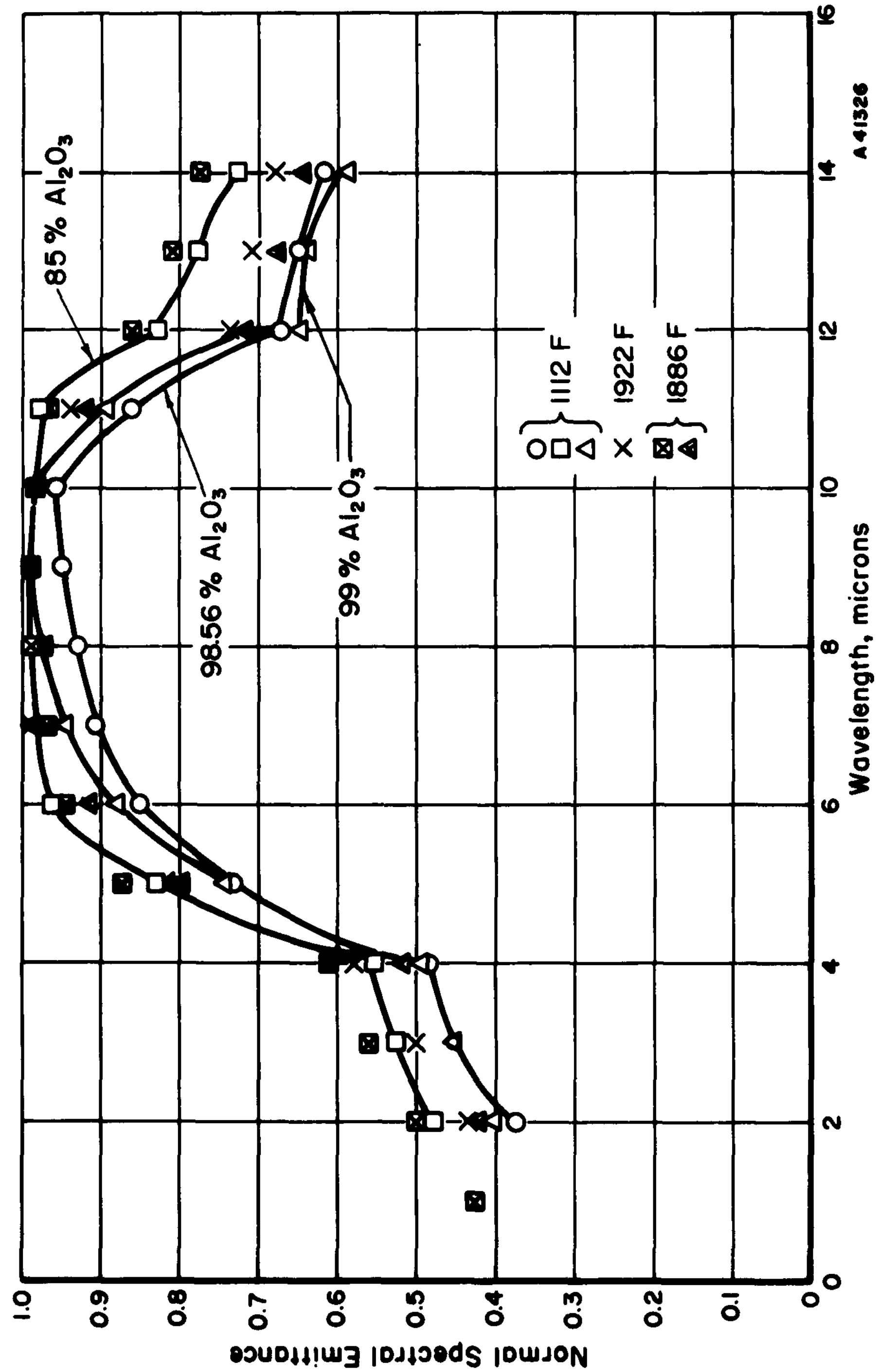
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris	△	Norton LA603 Aluminum oxide	Normal total emittance. Furnace-heated specimen. Comparison blackbody. Temperatures measured with thermocouples Thermistor detector.	Measured in air. Data taken from curves.
		○	Norton RA4213 Aluminum oxide		
			Surface condition not given		



NORMAL SPECTRAL EMITTANCE OF ALUMINUM OXIDE

NORMAL SPECTRAL EMITTANCE OF ALUMINUM OXIDE--REFERENCE INFORMATION

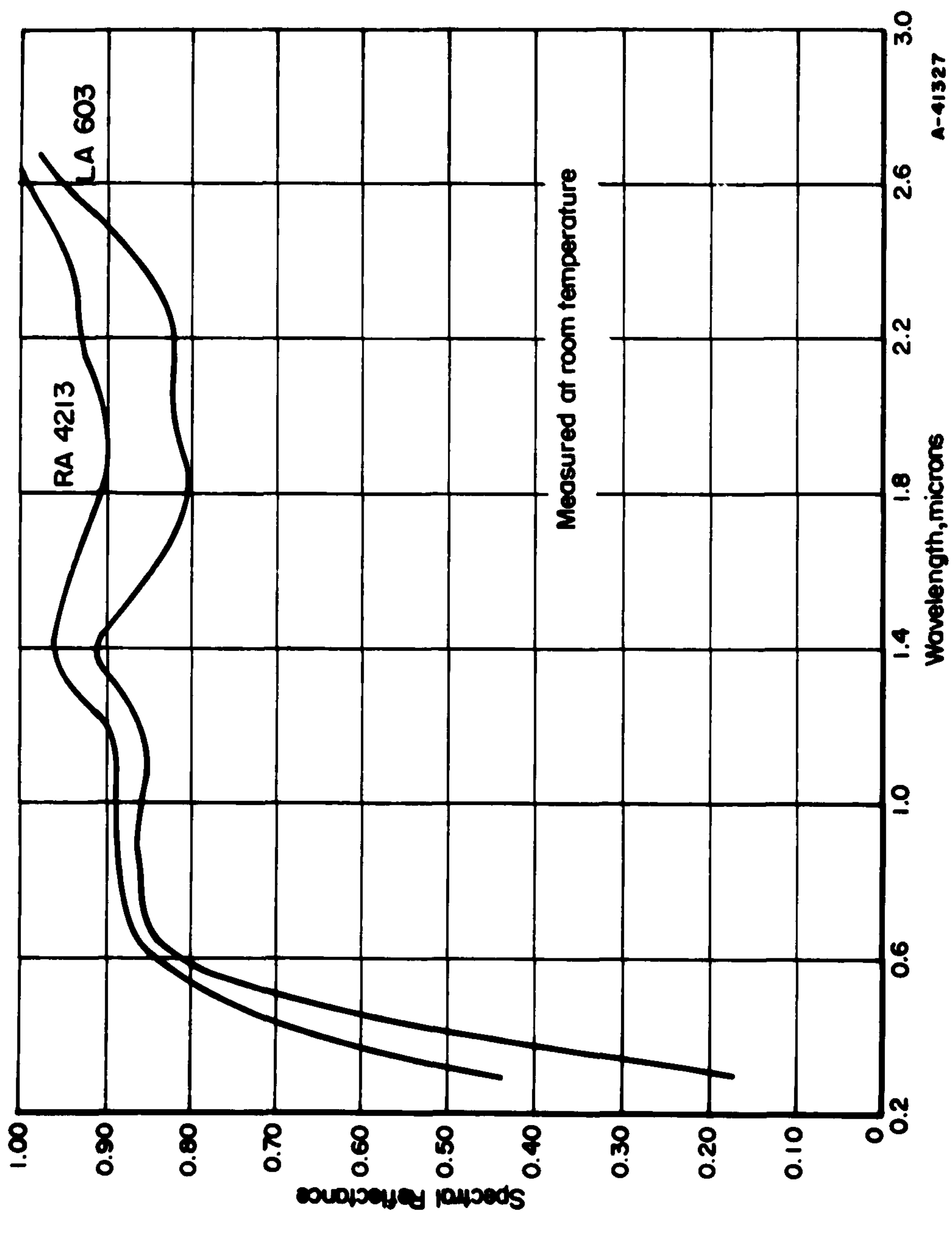
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris	○	Norton LA603 Aluminum oxide	Normal spectral emittance. Furnace-heated specimen. Comparison blackbody. Commercial radiation detector and filter system for peak response at 0.665μ. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.
		△	Norton RA4213 Aluminum oxide		($\lambda = 0.665\mu$)



NORMAL SPECTRAL EMITTANCE OF ALUMINUM OXIDE

NORMAL SPECTRAL EMITTANCE OF ALUMINUM OXIDE—REFERENCE INFORMATION

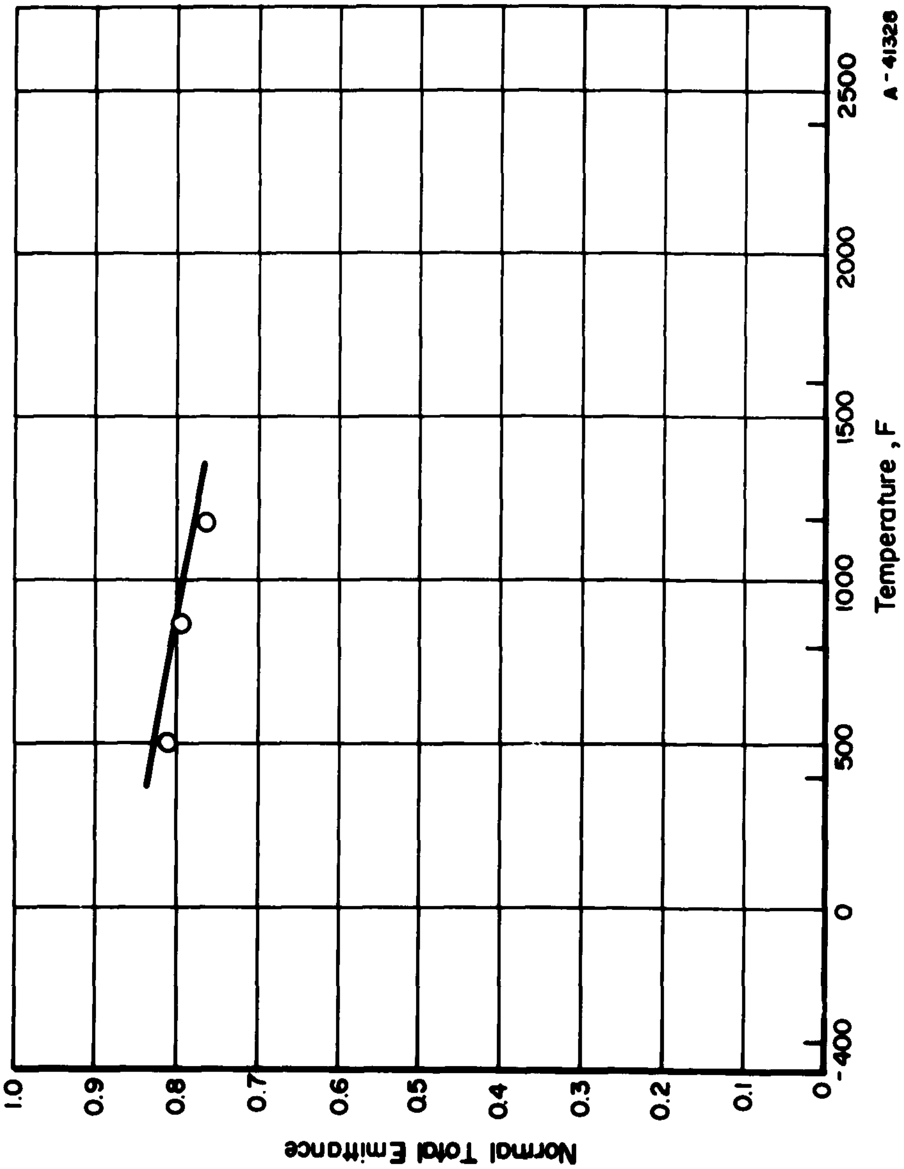
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
3	Blau, Marsh, Martin, Jasperse, and Chaffee		Aluminum oxide Diamond wheel finish as supplied by manufacturer TWA No. 2 (Norton A 402) 98.56% Al_2O_3	Normal spectral emittance. Specimen mounted in wall of cylindrical Globar (SiC) heater. Comparison blackbody hole also in heater. Temperatures measured with thermocouples. Monochromator and thermocouple detector.	Measured in air. Data taken from curves. (Curves are drawn through the 1112 F points only.)
		○	Measured at 1112 F		
		×	Measured at 1922 F		
			Coors AD85 85% Al_2O_3		
		□	Measured at 1112 F		
		⊠	Measured at 1886 F		
			Coors AD99 99% Al_2O_3		
		△	Measured at 1112 F		
		▲	Measured at 1886 F		



SPECTRAL REFLECTANCE OF ALUMINUM OXIDE

SPECTRAL REFLECTANCE OF ALUMINUM OXIDE--REFERENCE INFORMATION

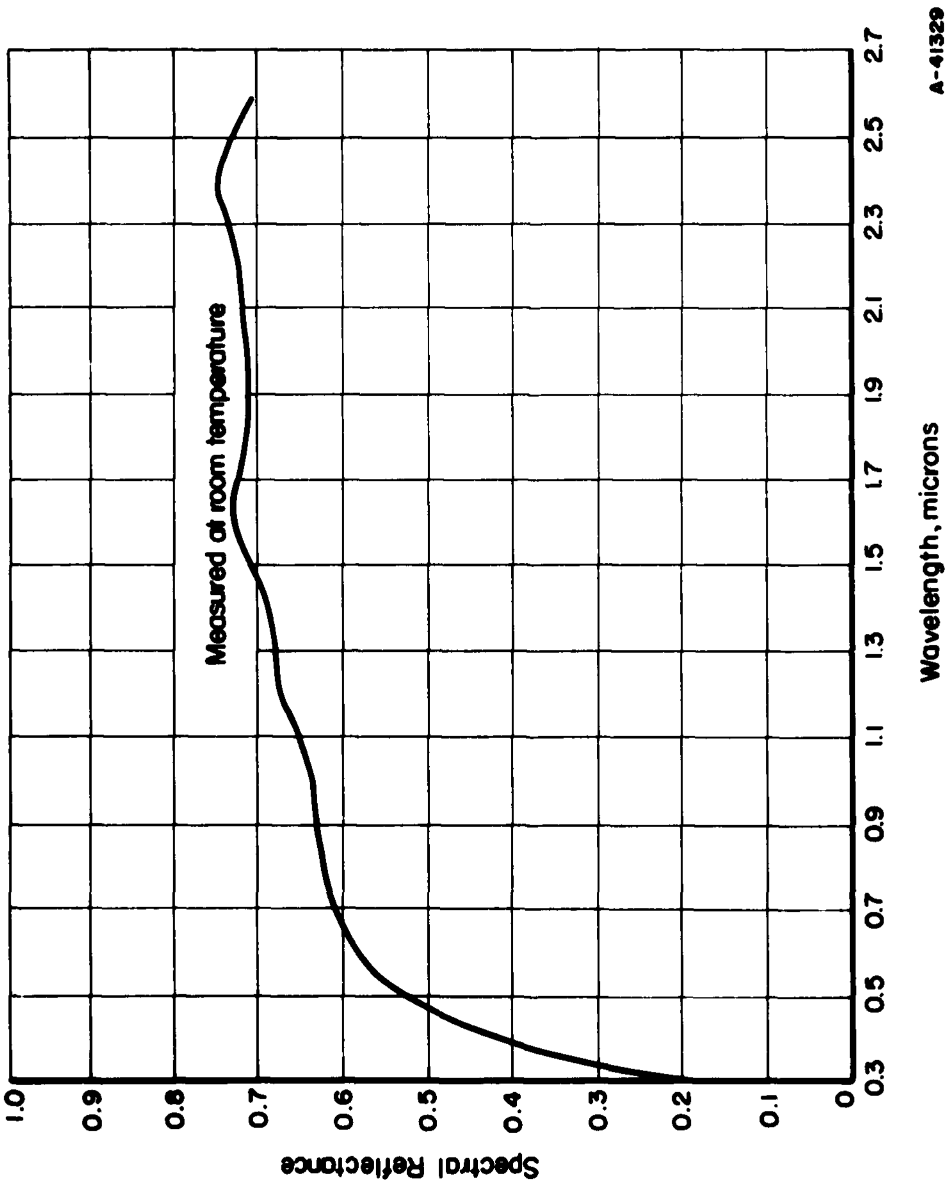
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris		Aluminum oxide Norton RA4213 and LA603 Surface condition not given	Spectral reflectance. Incident radiation 9 degrees from normal to specimen surface. Integrating sphere reflectometer. Monochromator and lead sulphide detector. Normal (9 degrees) illumination diffuse reflection.	Measured in air at room temperature. Data taken from curves.



NORMAL TOTAL EMITTANCE OF BERYLLIUM OXIDE

NORMAL TOTAL EMITTANCE OF BERYLLIUM OXIDE—REFERENCE INFORMATION

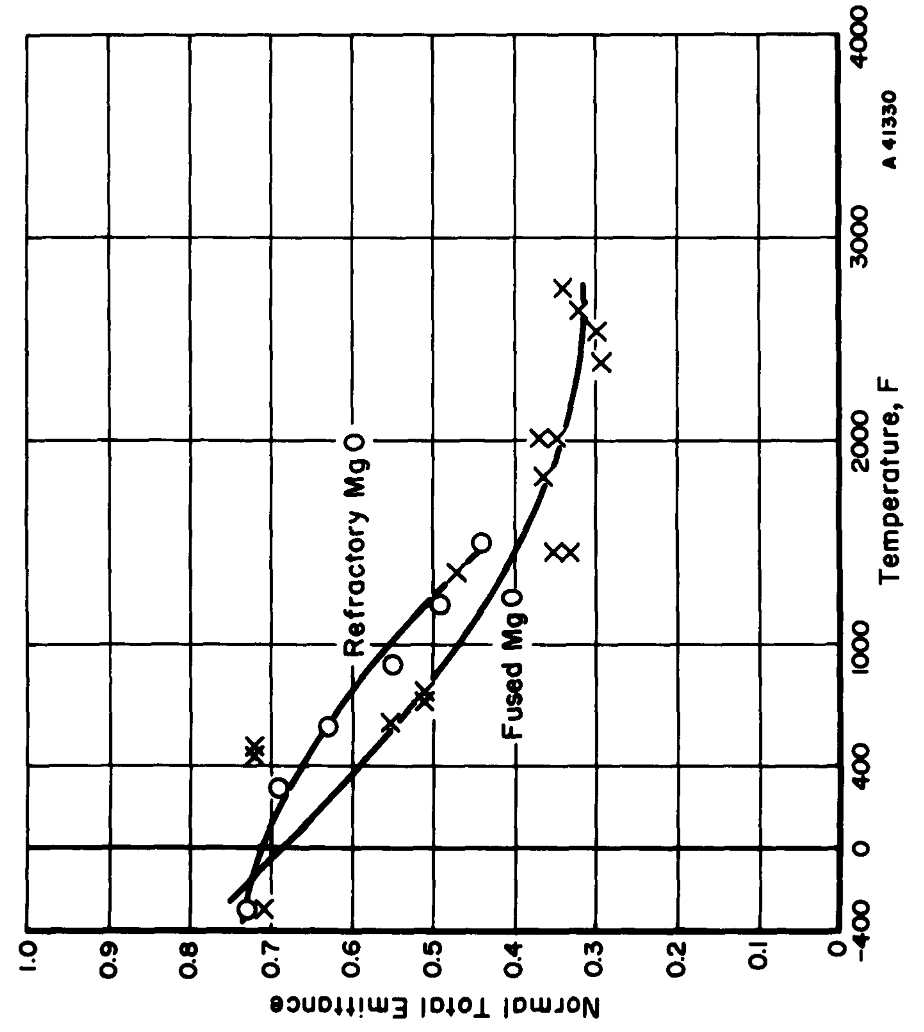
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris	O	Beryllium oxide	Normal total emittance. Furnace-heated specimen. Comparison blackbody. Thermistor detector. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.



SPECTRAL REFLECTANCE OF BERYLLIUM OXIDE

SPECTRAL REFLECTANCE OF BERYLLIUM OXIDE—REFERENCE INFORMATION

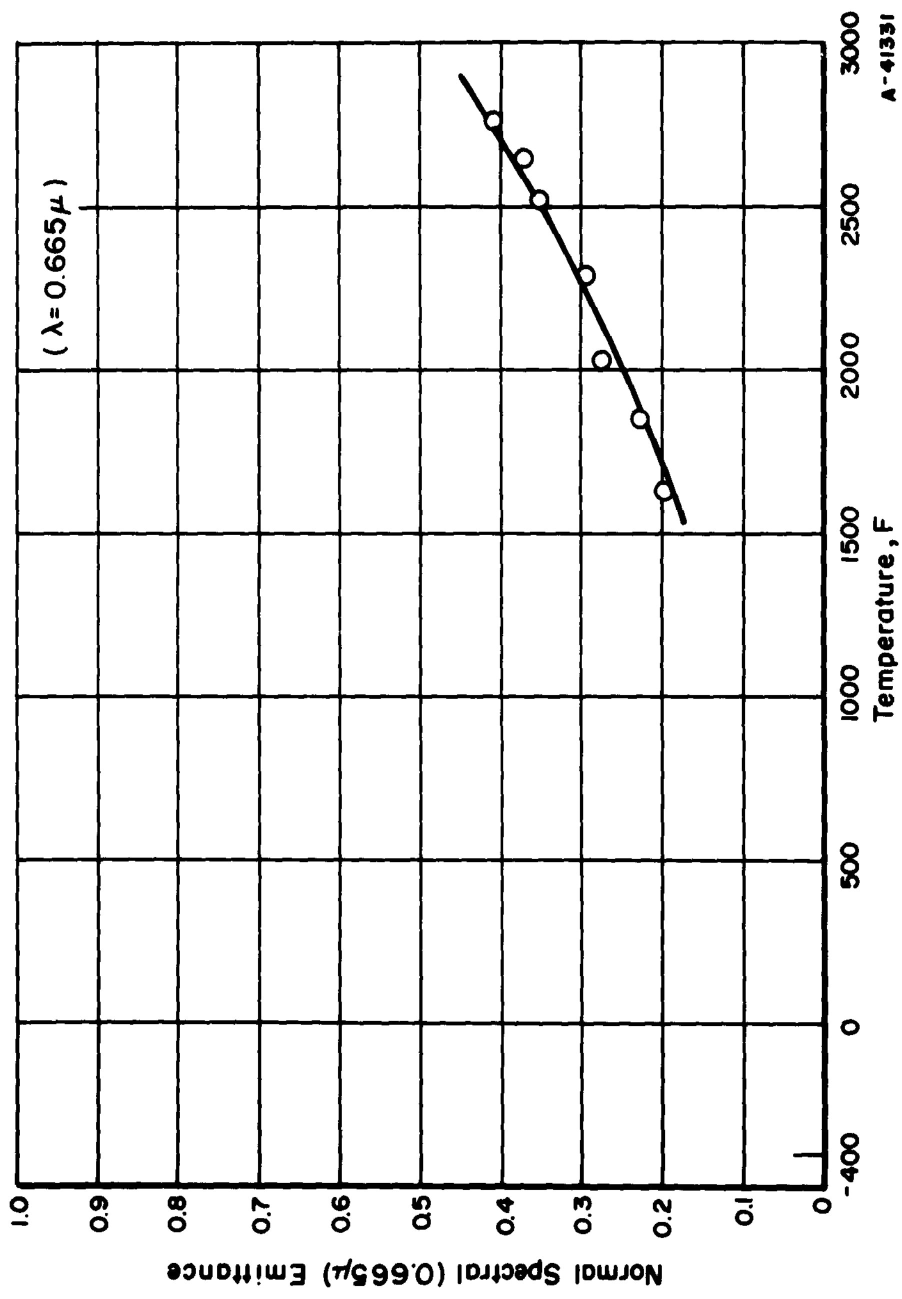
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
7	Betz, Olson, Schurin, and Morris		Beryllium oxide Purity not given As received condition	Spectral reflectance. Incident radiation 9 degrees from normal to specimen surface. Integrating sphere reflectrometer. Monochromator, and lead sulphide detector. Normal (9 degrees) illumination and diffuse reflection.	Measured in air at room temperature. Data taken from curves.



NORMAL TOTAL EMITTANCE OF MAGNESIUM OXIDE

NORMAL TOTAL EMITTANCE OF MAGNESIUM OXIDE--REFERENCE INFORMATION

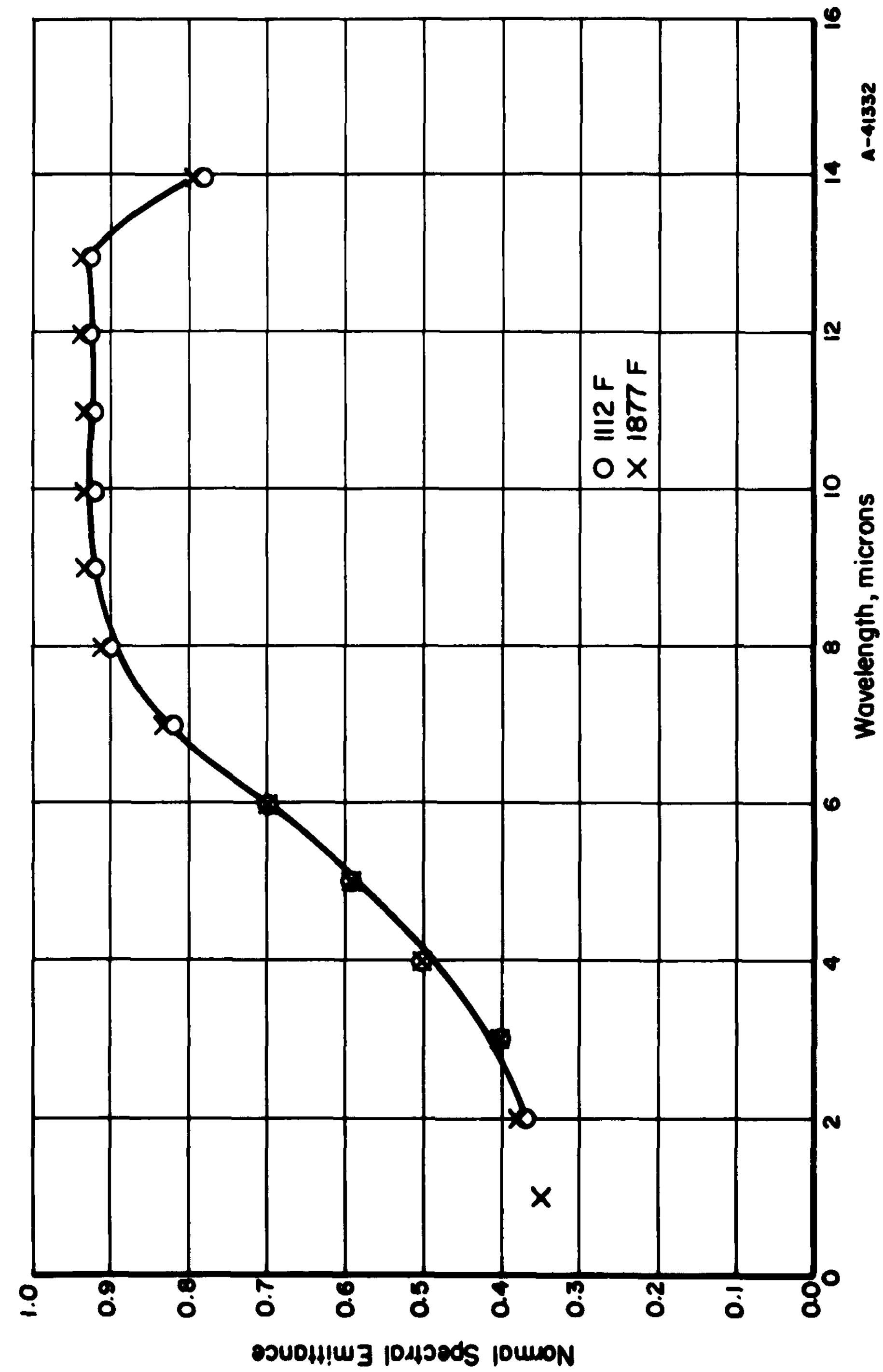
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris	×	Fused magnesium oxide obtained from the National Bureau of Standards. Surface condition not given	Normal total emittance. Furnace-heated specimen. Thermistor detector. Comparison blackbody. Temperatures measured with thermocouples.	Measured in air. Data taken from curve.
8	Olson and Morris	○	Refractory magnesium oxide Composition and surface condition not given	(Same as above.)	(Same as above.)



NORMAL SPECTRAL EMITTANCE OF MAGNESIUM OXIDE

NORMAL SPECTRAL EMITTANCE OF MAGNESIUM OXIDE—REFERENCE INFORMATION

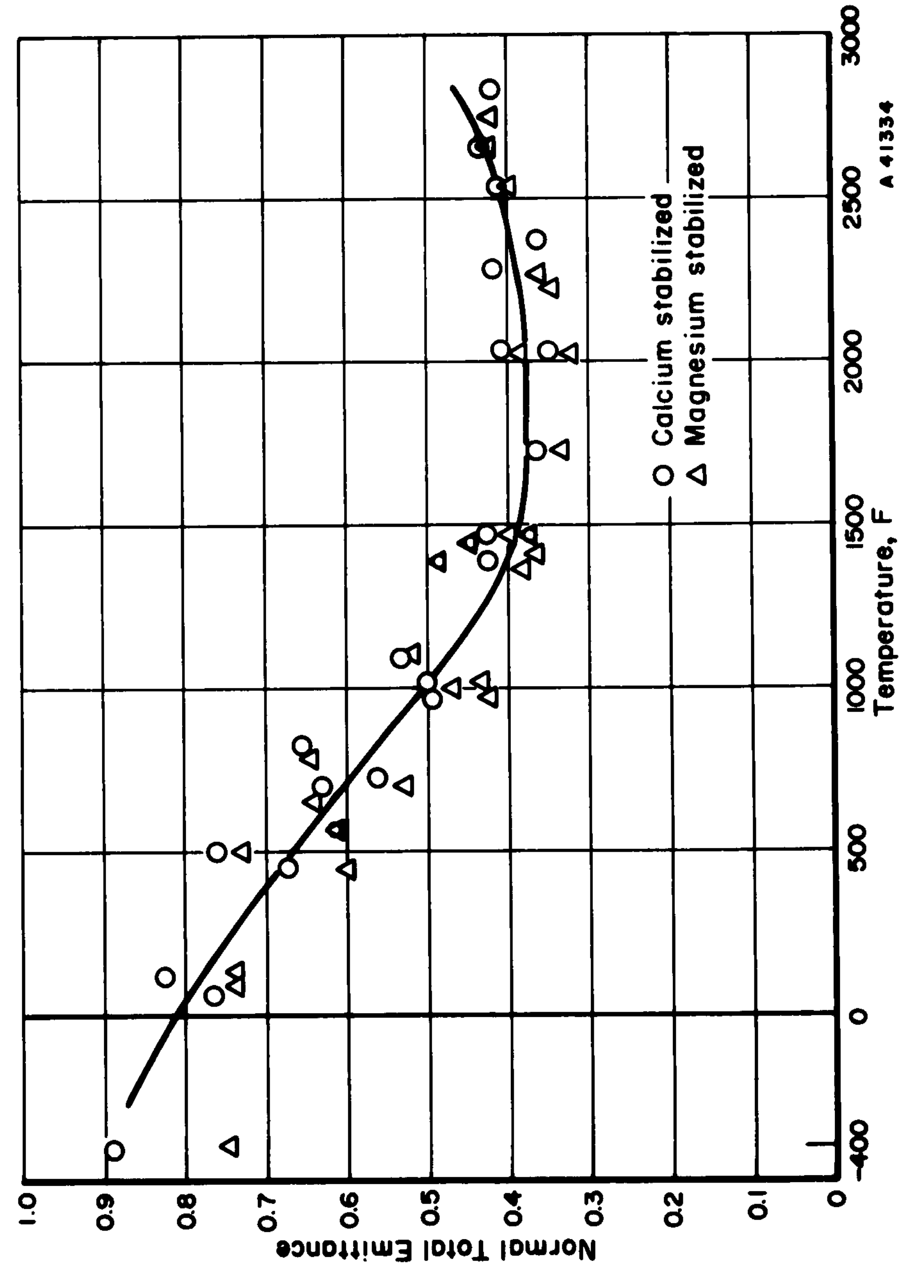
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris	O	Fused magnesium oxide obtained from National Bureau of Standards. Surface condition not given	Normal spectral emittance. Furnace-heated specimen. Comparison blackbody. Commercial detector and filter system for peak response at 0.665μ. Temperatures measured with thermocouples.	Measured in air. Data taken from curves. ($\lambda = 0.665\mu$)



NORMAL SPECTRAL EMITTANCE OF MAGNESIUM OXIDE

NORMAL SPECTRAL EMITTANCE OF MAGNESIUM OXIDE--REFERENCE INFORMATION

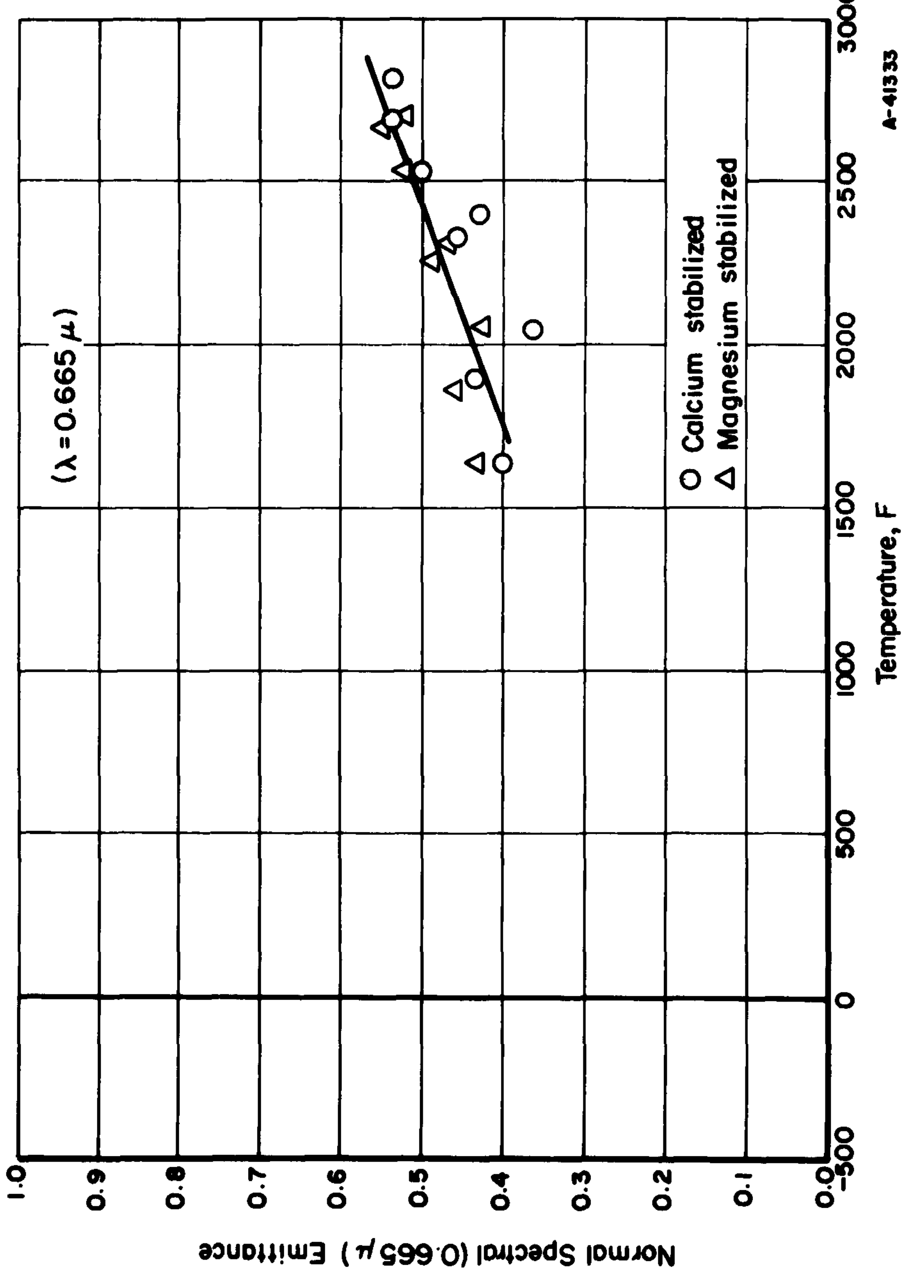
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
3	Blau, Marsh, Martin, Jasperse and Chaffee		Magnesia (MgO) Norton RM4473 Purity: 97% MgO, 1.3-1.5% CaO Surface condition not given	Normal spectral emittance. Specimen mounted in wall of cylindrical Globar (SiC) heater. Comparison blackbody hole in heater wall. Monochromator and thermocouple detector. Temperatures measured with thermocouples.	Measured in air. Data taken from curves. (Curve drawn through 1112 F points only.)
		O	Measured at 1112 F		
		X	Measured at 1877 F		



NORMAL TOTAL EMITTANCE OF ZIRCONIUM OXIDE

NORMAL TOTAL EMITTANCE OF ZIRCONIUM OXIDE--REFERENCE INFORMATION

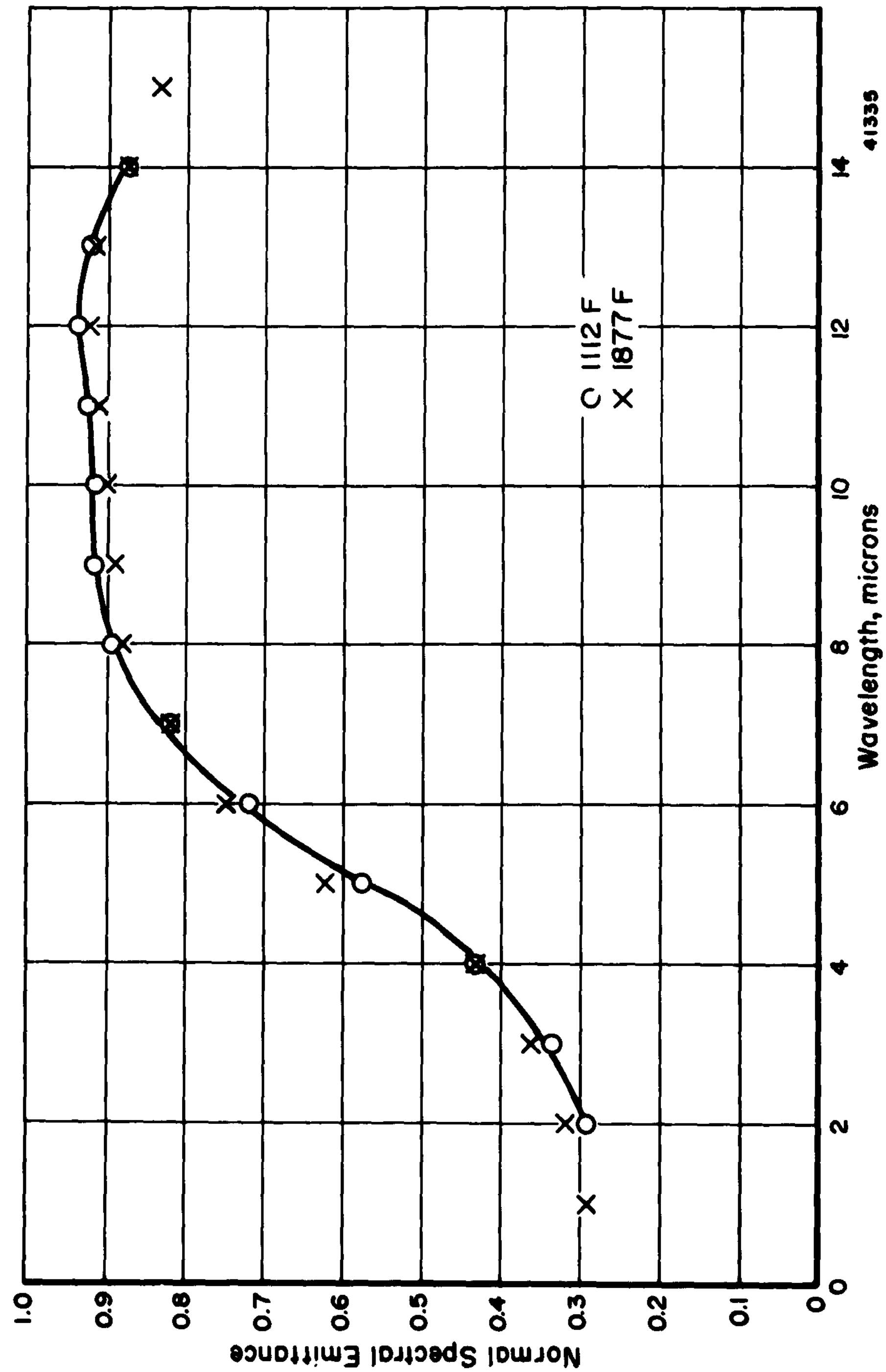
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris		Zirconium oxide	Normal total emittance. Furnace-heated specimen. Comparison blackbody. Thermistor detector. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.
		○	Calcium stabilized		
		△	Magnesium stabilized		



NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM OXIDE

NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM OXIDE--REFERENCE INFORMATION

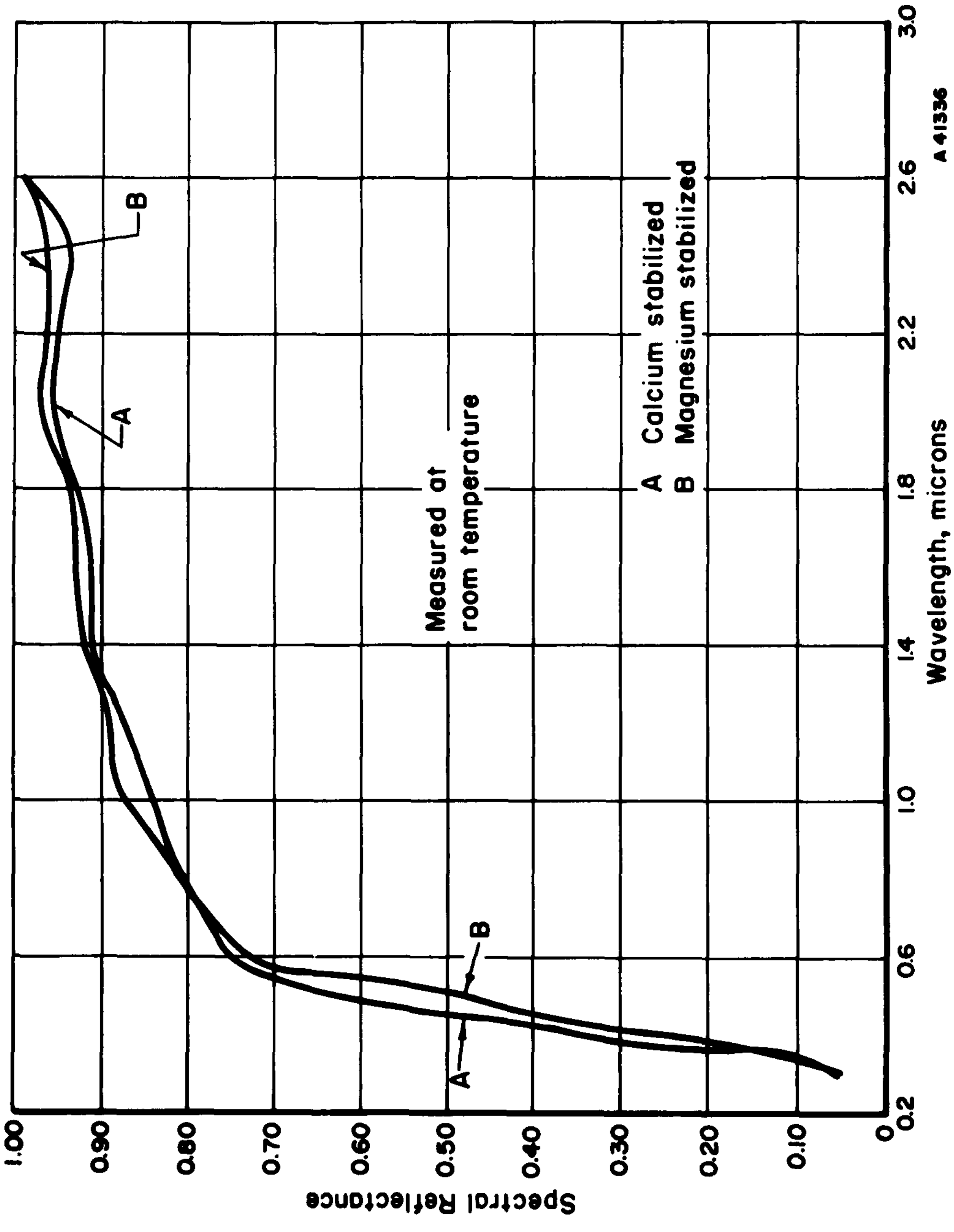
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris		Zirconium oxide	Normal spectral emittance. Furnace-heated specimen. Comparison blackbody. Commercial detector and filter system for peak response at 0.665μ. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.
		○	Calcium stabilized		
		△	Magnesium stabilized		$(\lambda = 0.665\mu)$



NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM OXIDE

NORMAL SPECTRAL EMITTANCE OF ZIRCONIUM OXIDE—REFERENCE INFORMATION

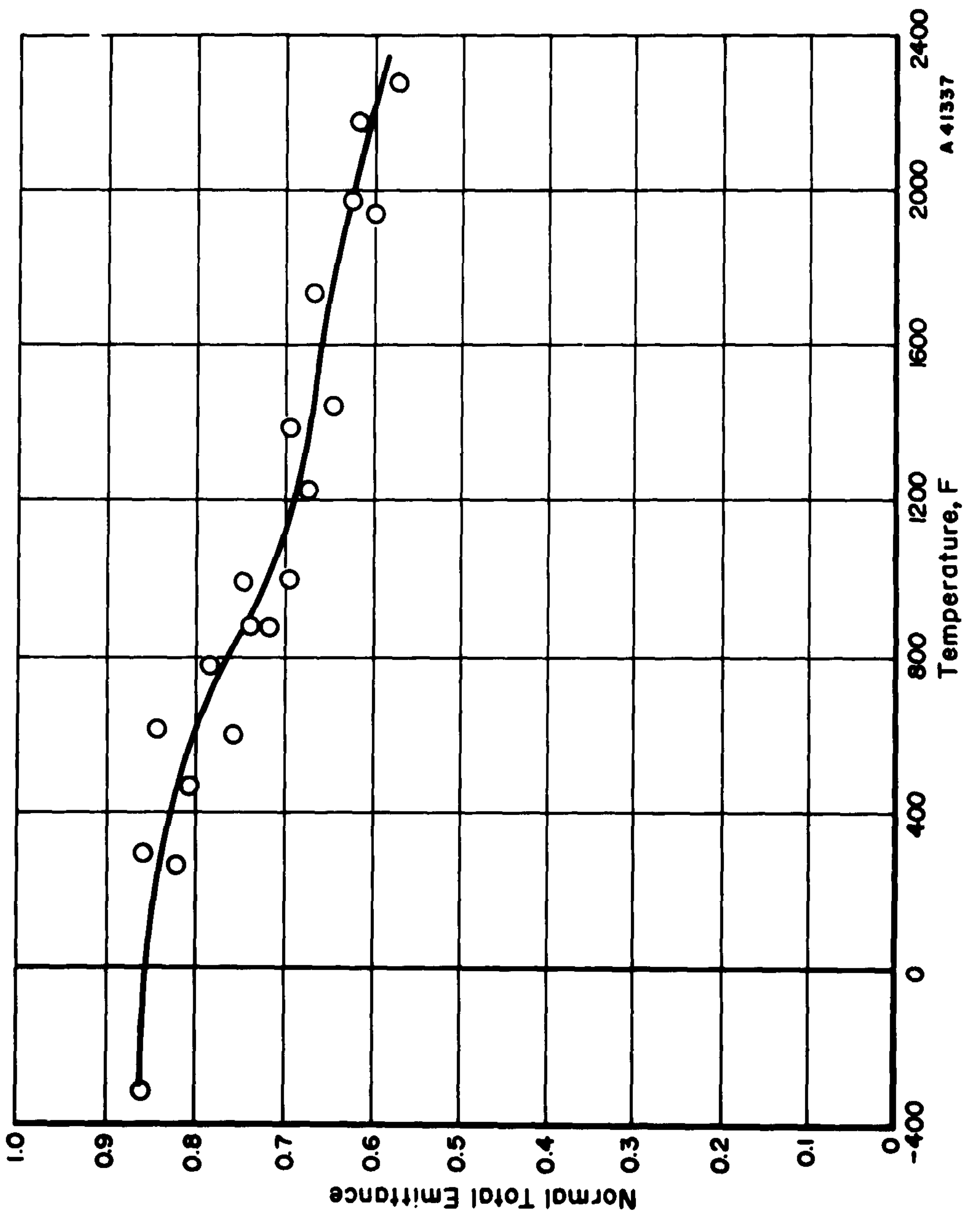
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
3	Blau, Marsh, Martin, Jasperse, and Chaffee		Zirconia (ZrO_2) Norton RZ 5601 Purity: 92% ZrO_2, 4.5% CaO Surface condition not given	Normal spectral emittance. Specimen mounted in wall of cylindrical Globar (SiC) heater. Comparison blackbody hole in heater wall. Monochromator and thermocouple detector. Temperatures measured with thermocouples.	Measured in air. Data taken from curves. (Curves drawn through 1112 F points only.)
		O	Measured at 1112 F		
		X	Measured at 1877 F		



SPECTRAL REFLECTANCE OF ZIRCONIUM OXIDE

SPECTRAL REFLECTANCE OF ZIRCONIUM OXIDE--REFERENCE INFORMATION

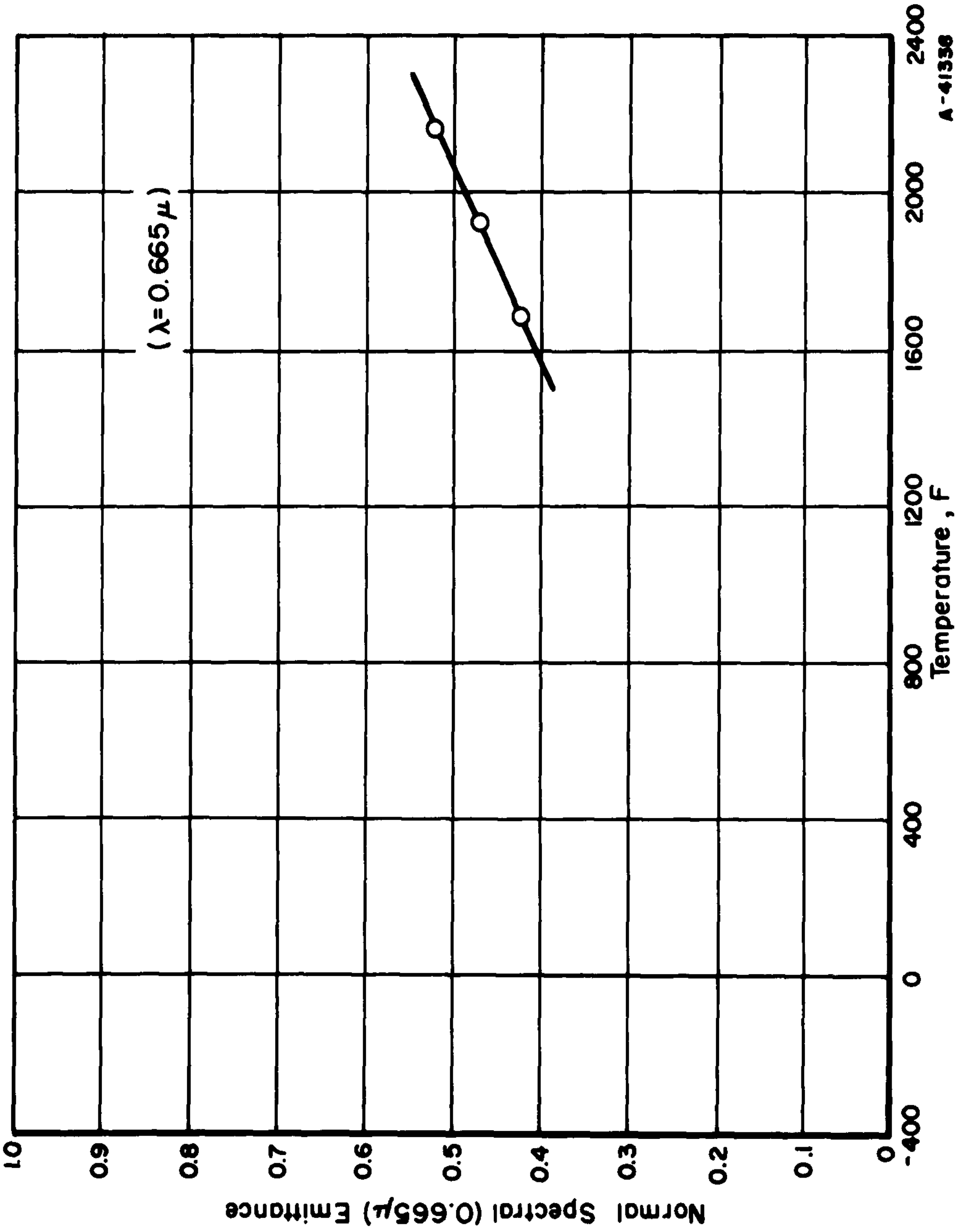
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris		Zirconium oxide Calcium stabilized and magnesium stabilized Purity and surface condition not given	Spectral reflectance. Incident radiation 9 degrees from normal to specimen surface. Integrating sphere reflectometer. Monochromator and lead sulphide detector. Normal (9 degrees) illumination. Diffuse reflection.	Measured in air at room temperature. Data taken from curves.



NORMAL TOTAL EMITTANCE OF PYROCERAM 9606

NORMAL TOTAL EMITTANCE OF PYROCERAM 9606--REFERENCE INFORMATION

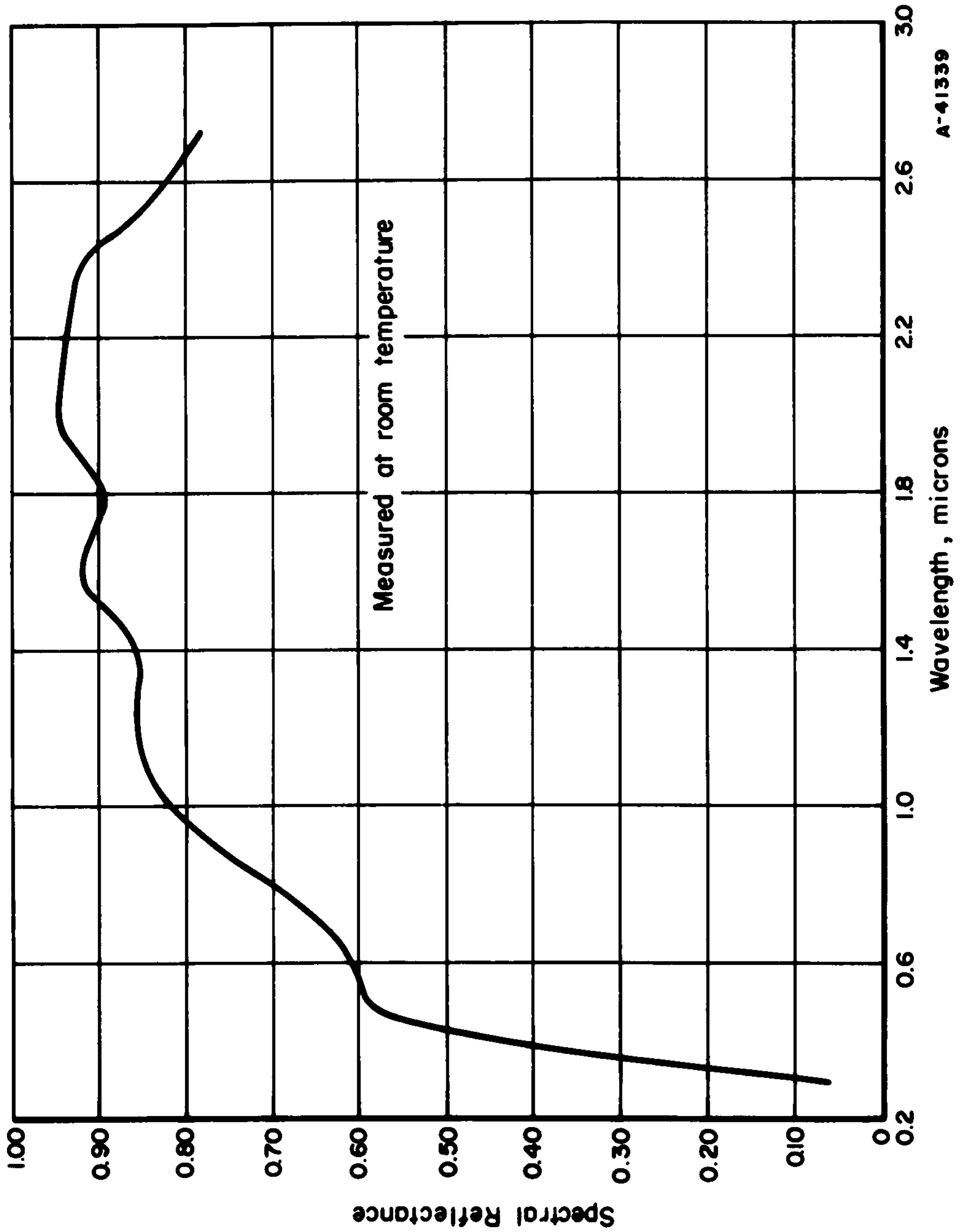
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris	O	Pyroceram 9606, surface condition not given	Normal total emittance. Furnace-heated specimen. Comparison blackbody. Thermistor detector. Temperatures measured with thermocouples.	Measured in air. Data taken from curves.



NORMAL SPECTRAL EMITTANCE OF PYROCERAM 9606

NORMAL SPECTRAL EMITTANCE OF PYROCERAM 9606--REFERENCE INFORMATION

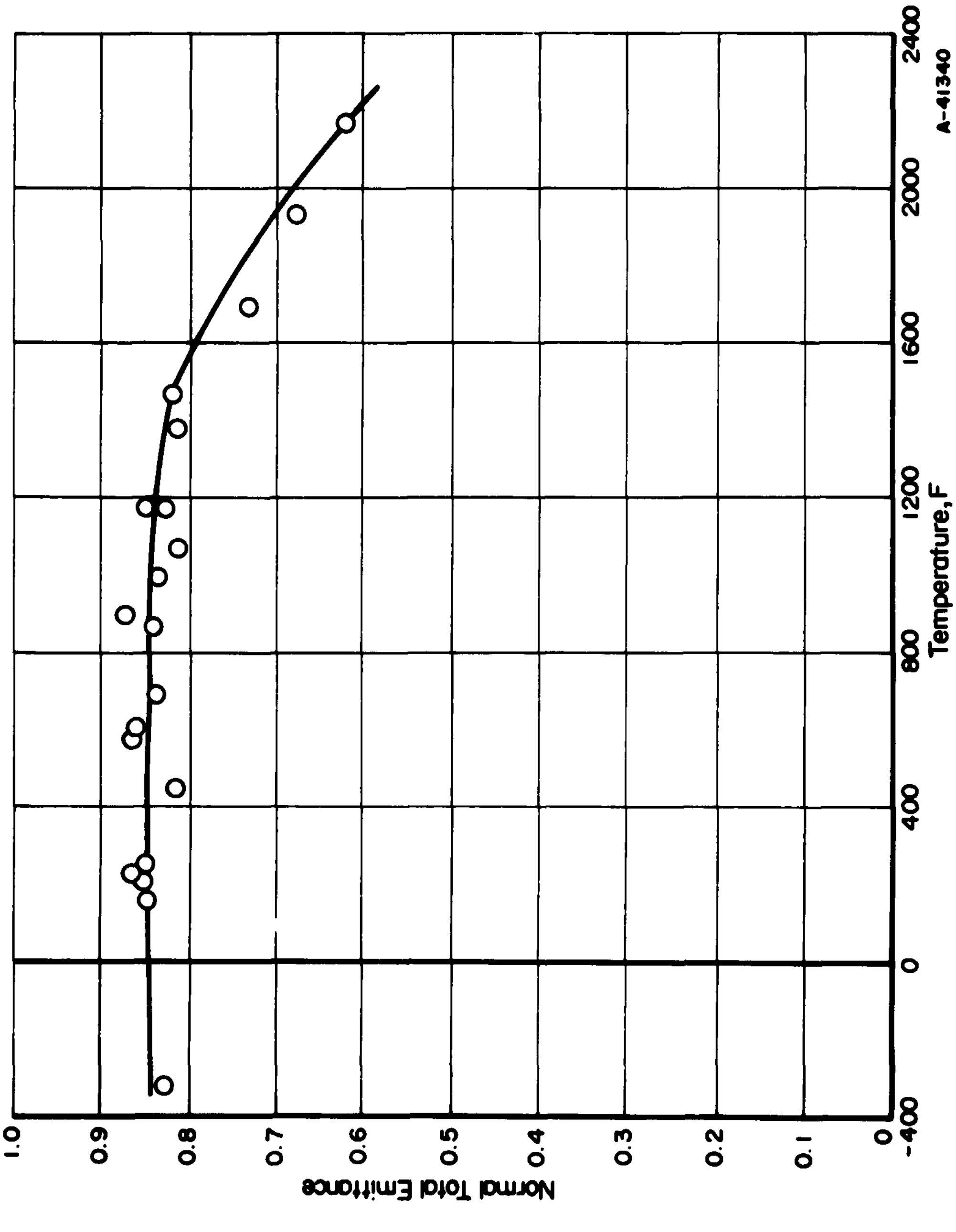
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris	O	Pyroceram 9606 Surface condition not given	Normal spectral emittance. Furnace-heated specimens. Comparison blackbody. Commercial detector and filter system for peak response at 0.665μ. Temperatures measured with thermocouples.	Measured in air. Data taken from curves. ($\lambda = 0.665\mu$)



SPECTRAL REFLECTANCE OF PYROCERAM 9606

SPECTRAL REFLECTANCE OF PYROCERAM 9606--REFERENCE INFORMATION

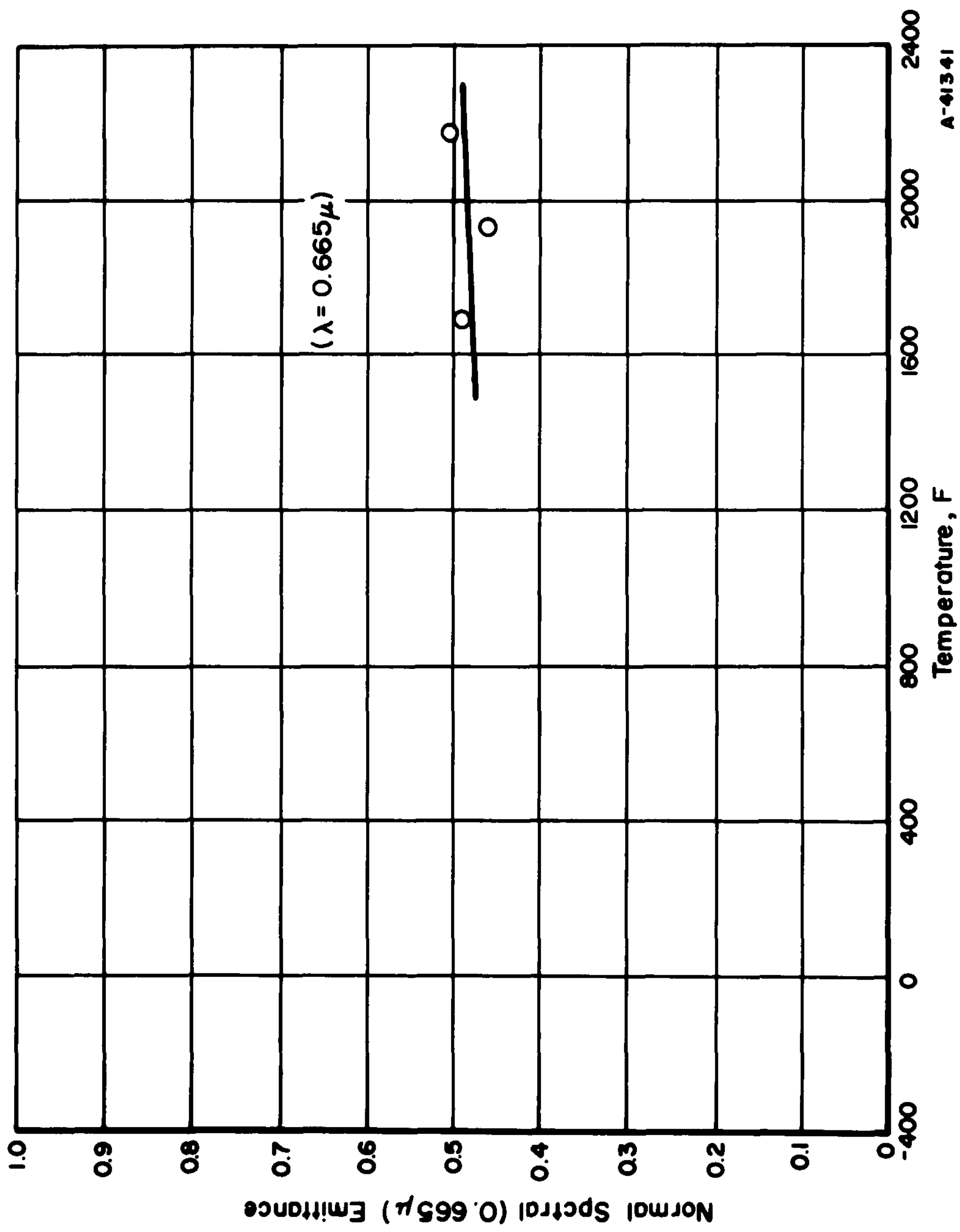
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris		Pyroceram 9606 Surface condition not given	Spectral reflectance. Incident radiation 9 degrees from normal to specimen surface. Integrating sphere reflectometer. Monochromator and lead sulphide detector. Normal (9 degrees) illumination. Diffuse reflection.	Measured in air at room temperature. Data taken from curves.



NORMAL TOTAL EMITTANCE OF PYROCERAM 9608

NORMAL TOTAL EMITTANCE OF PYROCERAM 9608—REFERENCE INFORMATION

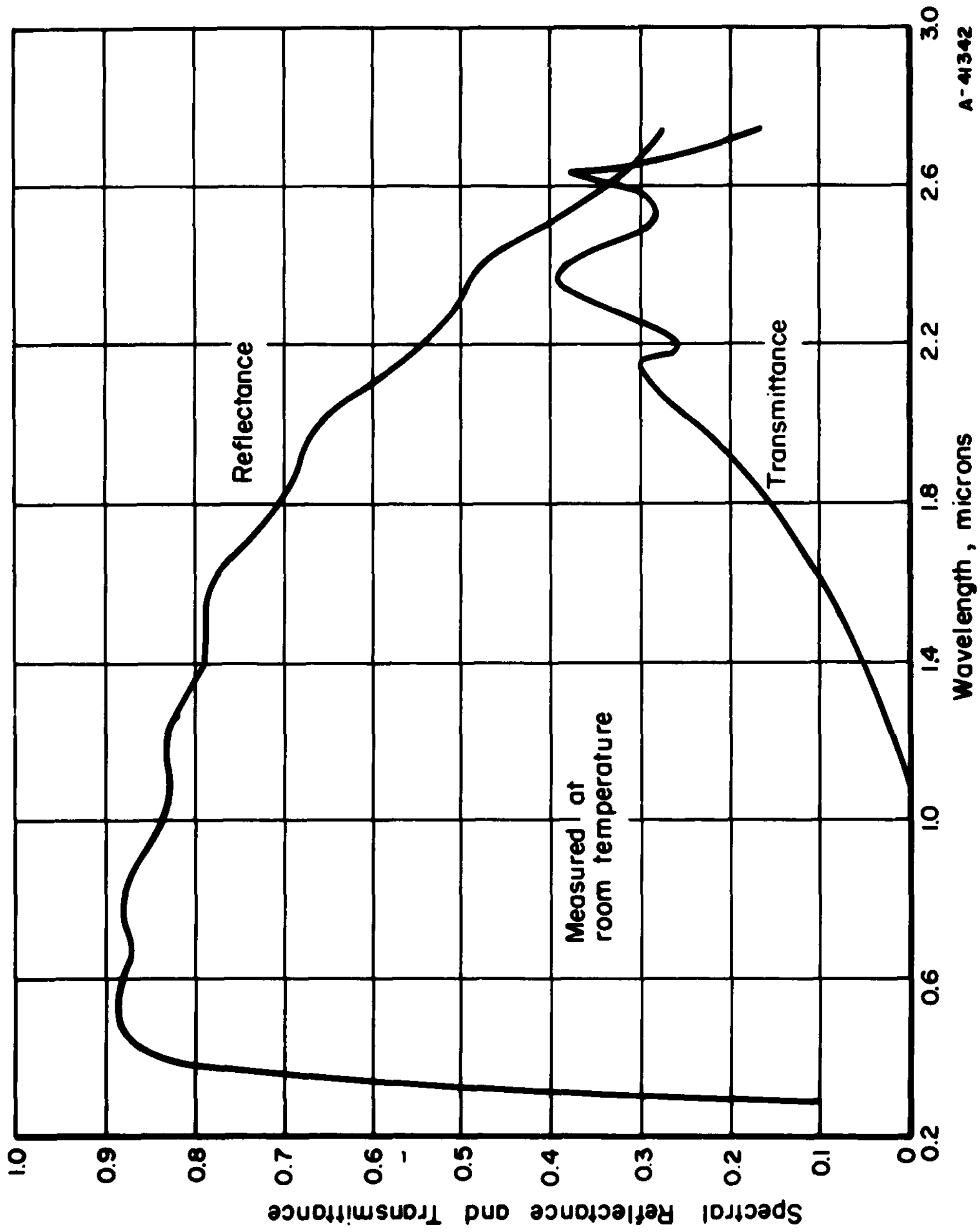
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris	O	Pyroceram 9608 Surface condition not given	Normal total emittance. Furnace-heated specimen. Comparison blackbody. Thermistor detector. Temperatures measured with thermocouples.	Measured in air. Data taken from curve.



NORMAL SPECTRAL EMITTANCE OF PYROCERAM 9608

NORMAL SPECTRAL EMITTANCE OF PYROCERAM 9608--REFERENCE INFORMATION

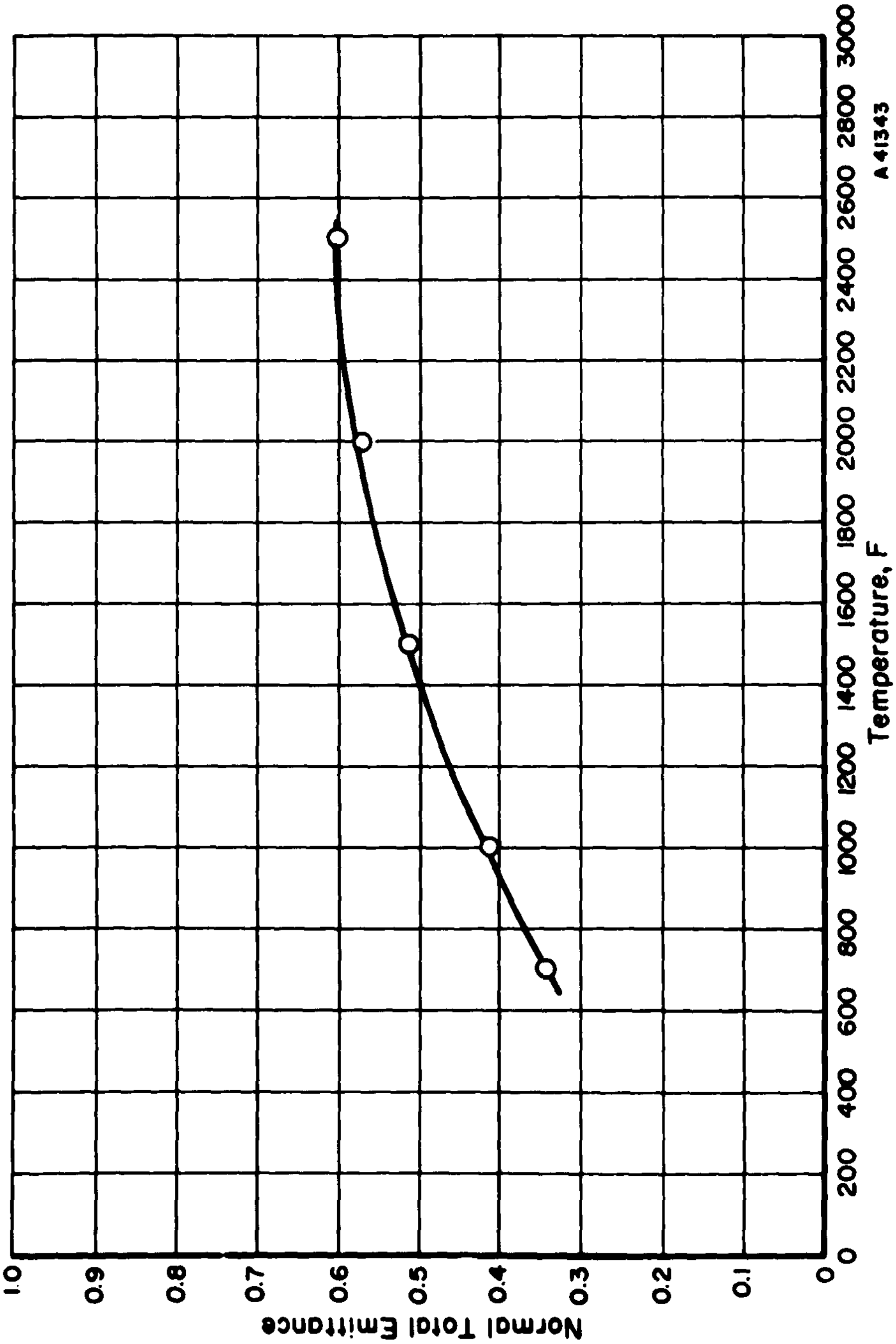
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris	O	Pyroceram 9608 Surface condition not given	Normal spectral emittance. Furnace-heated specimen. Comparison blackbody. Commercial detector and filter system for peak response at 0.665μ. Temperatures measured with thermocouples.	Measured in air. Data taken from curves. (λ= 0.665μ)



SPECTRAL REFLECTANCE AND TRANSMITTANCE OF PYROCERAM 9608

SPECTRAL REFLECTANCE AND TRANSMITTANCE OF PYROCERAM 9608—REFERENCE INFORMATION

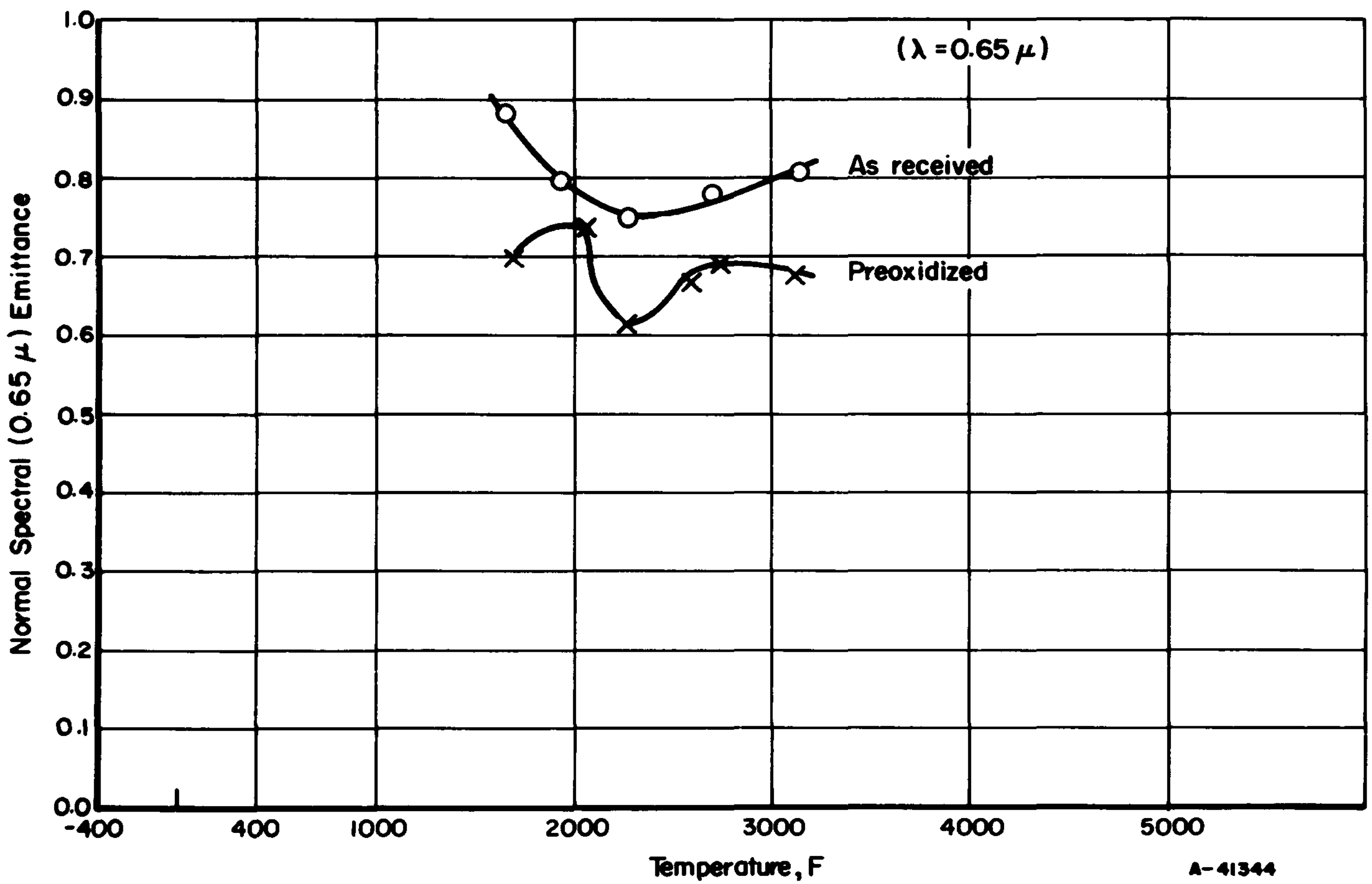
Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
2	Olson and Morris		Pyroceram 9608 Surfaces reasonably flat and parallel	<u>Spectral reflectance.</u> Incident radiation 9 degrees from normal to specimen surface. Integrating sphere reflectometer. Monochromator and lead sulphide detector. Normal (9 degrees) illumination. Diffuse reflection. <u>Spectral Transmittance.</u> Normal specimen position filled by $MgCO_3$ or MgO block. Specimen placed in entrance beam to sphere. Diffuse transmission.	Measured in air at room temperature. Data taken from curves.



NORMAL TOTAL EMITTANCE OF MOLYBDENUM DISILICIDE

NORMAL TOTAL EMITTANCE OF MOLYBDENUM DISILICIDE—REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
1	Anthony and Pearl	O	As received	Normal total emittance. Induction-heated specimen. Thermopile detector. Comparison blackbody. Temperatures measured with thermocouples and optical pyrometer.	Measured in continuous purge of helium gas.



NORMAL SPECTRAL EMITTANCE OF MOLYBDENUM DISILICIDE

NORMAL SPECTRAL EMITTANCE OF MOLYBDENUM DISILICIDE--REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
4	Blau, Chaffee, Jasperse, and Martin	O X	Molybdenum disilicide Surface clean and smooth Preoxidized (Lower emittance for the preoxidized surface attributed to SiO_2 surface layer)	Normal spectral emittance. Induction-heated specimen. Blackbody hole drilled in specimen surface. Temperatures measured with micro-optical pyrometer.	Measured in 90% argon - 10% hydrogen atmosphere. Data taken from curves. ($\lambda = 0.65\mu$)

TOTAL SOLAR ABSORPTANCES AT SEA LEVEL AND ABOVE THE ATMOSPHERE

	Finish	Above Atmosphere	Sea Level
Graphite-National GBE	(F)	0.850	0.863
Graphite-National GBE	(B)	0.869	0.877
Graphite-National GBH	(M)	0.881	0.887
Graphite-National GBH	(R)	0.885	0.891
Graphite-Speer 3474D	(M)	0.853	0.858
Graphite-Speer 3474D	(R)	0.866	0.871
Graphite-Speer 7087	(M)	0.908	0.911
Graphite-Speer 7087	(R)	0.916	0.918
Beryllium Oxide (Refractory)	(R)	0.421	0.405
Magnesium Oxide (Refractory)	(R)	0.168	0.141

TOTAL SOLAR ABSORPTANCE OF BERYLLIUM OXIDE, MAGNESIUM OXIDE AND THREE GRAPHITES—REFERENCE INFORMATION

Reference	Investigator	Symbol	Composition and Surface Condition	Test Method	Remarks
7	Betz, Olson, Schurin, and Morris		Surface finishes: B* back F* front M fine milling machine cut R as received from supplier. * back and front surfaces arbitrarily assigned to graphite sample. Sides appeared different to the eye.	Solar absorptance calculated by method of truncated weighted ordinate integration using spectral reflectance vs wavelength curves and solar energy distribution curves over the limits of 0.3 to 2.4 microns. Above atmosphere values corrected for 3 per cent of energy lying outside these limits.	Calculated. Data obtained from table.

REFERENCES

(1) Anthony, F. M. and Pearl, Harry A., "Investigations of Feasibility of Utilizing Available Heat Resistant Materials for Hypersonic Leading Edge Applications" (Vol. III - Screening Test Results and Selection of Materials), WADC TR 59-744 (July, 1960).

(2) Olson, O. H. and Morris, J. C., "Determination of Emissivity and Reflectivity Data on Aircraft Structural Materials", Part III - Techniques for Measurement, WADC TR 56-222, ASTIA AD 239302 (April, 1960).

(3) Blau, H. H., Jr., Marsh, J. B., Martin, W. S., Jasperse, J. R. and Chaffee, E., "Infrared Spectral Emittance Properties of Solid Materials", AFCRL-TR-60-416, ASTIA AD 248276 (October, 1960).

(4) Blau, H. H., Jr., Chaffee, E., Jasperse, J. R., and Martin, W. S., "High Temperature Thermal Radiation Properties of Solid Materials", AFCRC-TN-60-165, ASTIA AD 236394 (March 31, 1960).

(5) Coffman, J. A., Coulson, K. L. and Kibler, T. M., General Electric Company, Cincinnati, Ohio, preliminary information under an Air Force contract.

(6) Riethof, T. R., "High Temperature Spectral Emissivity Studies", General Electric Company MSVD, Space Sciences Laboratory, R61SD004 (January, 1961).

(7) Betz, H. T., Olson, O. H., Schurin, B. D. and Morris, J. C., "Determination of Emissivity and Reflectivity Data on Aircraft Structural Materials", Part II: Techniques for measurement of total normal spectral emissivity, solar absorptivity, and presentation of results. WADC TR 56-222, ASTIA AD 202493.

(8) Olson, O. H. and Morris, J. C., "Determination of Emissivity and Reflectivity Data on Aircraft Structural Materials", WADC TR 56-222, Part II Supplement I, ASTIA 202494 (October, 1958).

(9) Jain, S. C. and Krishnan, Sir F.R.S., "The Distribution of Temperature Along a Thin Rod Electrically Heated in Vacuo", Proc. Royal Soc. London, Vol. 225, pp 7-19 (1954).

(10) Thorn, R. J. and Simpson, O. C., "Spectral Emissivities of Graphite and Carbon", Jour. of Applied Physics, Vol. 24, No. 5, pp 633-639 (May, 1953).

(11) Wade, W. R. and Casey, F. W., Jr., "Measurements of Total Hemispherical Emissivity of Several Stably Oxidized Nickel-Titanium Carbide Cemented Hard Metals From 600° to 1600° F", NASA Memo 5-13-59L.

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A list of DMIC Memoranda 1-117 may be obtained from DMIC, or see previously issued memoranda.

DMIC Memorandum Number	Title
118	Review of Recent Developments in the Metallurgy of High-Strength Steels, July 21, 1961, (AD 259986 $0.50)
119	The Emittance of Iron, Nickel, Cobalt and Their Alloys, July 25, 1961, (AD 261336 $2.25)
120	Review of Recent Developments on Oxidation-Resistant Coatings for Refractory Metals, July 31, 1961, (AD 261293 $0.50)
121	Fabricating and Machining Practices for the All-Beta Titanium Alloy, August 3, 1961, (AD 262496 $0.50)
122	Review of Recent Developments in the Technology of Nickel-Base and Cobalt-Base Alloys, August 4, 1961, (AD 261292 $0.50)
123	Review of Recent Developments in the Technology of Beryllium, August 18, 1961, (AD 262497 $0.50)
124	Investigation of Delayed-Cracking Phenomenon in Hydrogenated Unalloyed Titanium, August 30, 1961
125	Review of Recent Developments in Metals Joining, September 1, 1961, (AD 262905 $0.50)
126	A Review of Recent Developments in Titanium and Titanium Alloy Technology, September 15, 1961
127	Review of Recent Developments in the Technology of Tungsten, September 22, 1961
128	Review of Recent Developments in the Evaluation of Special Metal Properties, September 27, 1961
129	Review of Recent Developments in the Technology of Molybdenum and Molybdenum-Base Alloys, October 6, 1961
130	Review of Recent Developments in the Technology of Columbium and Tantalum, October 10, 1961
131	Review of Recent Developments in the Technology of High-Strength Stainless Steels, October 13, 1961
132	Review of Recent Developments in the Metallurgy of High-Strength Steels, October 20, 1961
133	Titanium in Aerospace Applications, October 24, 1961
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146	Magnesium-Lithium Alloys - A Review of Current Developments, February 6, 1962
147	An Evaluation of Materials for Rocket-Motor Cases Based on Minimum Weight Concepts, March 8, 1962